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TECHNICAL REPORT

CORN/SOYBEAN DECISION LOGIC: IMPROVEMENTS AND NEW CROPS

C. L. Dailey, K. M. Abotteen, and J. D. Nichols

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TECHNICAL REPORT

CORN/SOYBEAN DECISION LOGIC: IMPROVEMENTS AND NEW CROPS

Job Order 74-413

This report describes Multicrop Classification Technology activities of the Foreign Commodity Production Forecasting project of the AgRISTARS program.

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16. Abstract

This report addresses three subjects. First, recommendations for improvement of the Transition Project corn/soybean decision logic are offered after examination of labeling errors from the Multicrop Exploratory Experiment and the Simulated Aggregation Test. Second, initial requirements for automation of the corn/soybean decision logic are presented in flow chart form. Third, results from a preliminary study of cotton, rice, and sunflowers are documented.

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PREFACE

This report addresses three subjects. First, recommendations for improvement of the Transition Project corn/soybean decision logic are offered after examination of labeling errors from the Multicrop Exploratory Experiment and the Simulated Aggregation Test. Second, initial requirements for automation of the corn/soybean decision logic are presented in flow chart form. Third, results from a preliminary study of cotton, rice, and sunflowers are documented.

Several coworkers contributed significantly to the data reduction and analysis necessary to complete this project. D. C. Helmer, J. M. Jones, and C. J. Ramirez evaluated labeling errors and gathered spectral and growth stage information for the new crop research. H. C. Breigh plotted mean spectral information for a variety of crop categories. Their assistance with this study was greatly appreciated.

Also, the authors would like to thank R. M. Bizzell and L. C. Wade of the National Aeronautics and Space Administration for the constructive criticism they offered in their review of this report.

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1. INTRODUCTION

This report documents the work that has been done on labeling decision logic. Specifically, improvements to the Transition Project corn/soybean decision logic for the U.S. Corn Belt are described and requirements to automate parts of this decision logic are documented. Also, cotton, rice, and sunflowers have been examined for trends and characteristics that would allow their incorporation into the present decision logic tree or, if applicable, for the development of new crop decision logic.

1.1 BACKGROUND

A procedure for identifying and labeling corn and soybean crops was developed during the Transition Project for application in the U.S. Corn Belt (Iowa, Illinois, Indiana, Missouri) (ref. 11). This procedure, contained in appendix A, consists of a series of decision points, arranged in a tree-like structure, the branches of which lead an analyst to crop identification decisions.

The structure of the Transition Project decision logic was designed to allow for the automation of as many steps as possible. An example of a step which might be automated was the decision that an analyst had to make about the color of a pixel. If automation of some of the steps could be achieved, the objectivity of the decision would be greatly increased. The procedure also lends itself to the study of critical error sources.

The corn/soybean decision logic structure was developed and tested in the U.S. Corn Belt. It will now be extended to new crops and other areas of the country. Cotton, rice, and sunflowers were chosen as the new crops for several reasons. The crops of major concern are grown in some of the foreign regions to be studied in AgRISTARS and are important to the economy of certain regions in the United States. These crops also cause confusion in the labeling technology that had already been developed. Specifically, crops which had similar growth cycles were rice and other small grains, cotton and soybeans, and sunflowers and corn and/or soybeans. The extent of confusion and possible solutions needed to be investigated. Finally, sufficient Landsat imagery with

accompanying ground truth information was available to make a preliminary study feasible.

1.2 OBJECTIVES

The major objectives of this investigation were to correct and improve the Transition Project corn/soybean decision logic, to define requirements for automation of some of the steps, and to extend the decision logic to include other crops and new areas. The specific objectives were to

- Characterize errors in terms of each step of the corn/soybean decision logic
- Improve the decision logic steps whenever errors were found to be significant
- Recommend automation requirements for the corn/soybean decision logic where applicable
- Determine the separability of cotton, rice, and sunflowers from confusion crops in the scene
- Incorporate cotton, rice, and sunflowers into the decision logic if possible
- Collect information on new crops and make recommendations for further study

2. TRANSITION PROJECT DECISION LOGIC

The Transition Project corn/soybean decision logic (appendix A) was used in the Multicrop Exploratory Experiment and the Simulated Aggregation Test (refs. 2, 4, 7, 14). Seventy-five segments in these tests had ground-truth available for evaluating the labels. Table 1 shows the confusion matrix and accuracies for the pure small dots.

The errors were characterized according to the step in which they occurred. The errors were distributed as follows:

Step 1	19/117	16%
Step 2	36/117	31%
Step 3	20/117	17%
Step 4	20/117	17%
Human and clerical	22/117	19%

The segments were examined to see if a common cause of error could be identified. When consistent problems were discovered, solutions were recommended.

2.1 IMPROVEMENTS

2.1.1 STEP 1 — SEPARATION OF MAJOR LAND USE CATEGORIES

The majority of the errors in step 1 were attributed to poor acquisition histories and the subjectivity of the analyst's determination of the colors on the imagery. As an aid to the analyst's labeling, major land use definitions and characteristics were presented with the decision tree. Spectral characteristic descriptions will supplement the major land use category descriptions for the categories that had sufficient data to observe; i.e., pasture, forest, and water.

TABLE 1.– CONFUSION MATRIX AND ACCURACIES FOR PURE SMALL DOTS FROM CORN/SOYBEAN TESTS

Ground truth	Analyst Corn	Soybeans	Other	Total
Corn	1197	21	75	1293
Soybeans	62	790	50	902
Other	23	9	755	787
Total	1282	820	880	2982

Accuracy	P(Corn/Corn)	.9258
	P(Soybeans/Soybeans)	.8758
	P(Other/Other)	.9593
Errors of commission	P(Corn/Other)	.0294
	P(Soybeans/Other)	.0114
	P(Corn or Soybeans/Other)	.0406
Errors of omission	P(Other/Corn)	.0580
	P(Other/Soybeans)	.0554
	P(Other/Corn or Soybeans)	.0569
Confusion	P(Corn/Soybeans)	.0687
	P(Soybeans/Corn)	.0162

Figure 1a and b shows the green number versus time and brightness versus time plots* for all the segments with pasture. Pasture tended to remain fairly constant in brightness from spring until midsummer when it began to decrease. Its green number rose steadily to midsummer and then slowly decreased. Figure 2a and b shows the green number and brightness versus time plots for forest. Forest also remained fairly constant in brightness from spring until midsummer when its brightness began to decrease. However, the green number fell steadily from spring through the fall. Figures 2a and 3 are the green number and brightness versus time plots for water. Both green number and brightness tended to be very constant with the green number normally below the soil line.

It was found that the actual purpose of step 1 was not clearly worded and was frequently misunderstood by the analyst. Therefore, the following will be added to the procedure as an introduction.

> This step was developed to diagram the logical thought process necessary to achieve identification of major land uses from Landsat imagery. The principal purpose is to offer the analyst a logical approach to extracting the first level of information necessary to define specific agricultural crops. By following this tree, the analyst identifies cropland signatures and eliminates all other signatures from further decisionmaking. This diagram is also to be used by less experienced analysts to aid in learning the technique of going from the general to the refined categories in a consistent manner.
>
> Each major land use category is accompanied by a general description and spectral properties which allow the analyst to decide if the tree has indeed led to the proper decision. The tree accounts for the information offered on Landsat imagery (film product 1). Although it is not necessary for this decision logic, the analyst should always be familiar with the variety of ancillary data available which include historical crop statistics, meteorological summaries, and maps. The analyst should also use other spectral information offered in film product 3 and in the spectral aids, especially if there is evidence of inconsistencies in product 1. When the label derived from the decision tree is contradicted by other available data, the discrepancy should be noted on the labeling form.

*The spectral plots are not Sun-angle corrected. The general description might change if corrections were made.

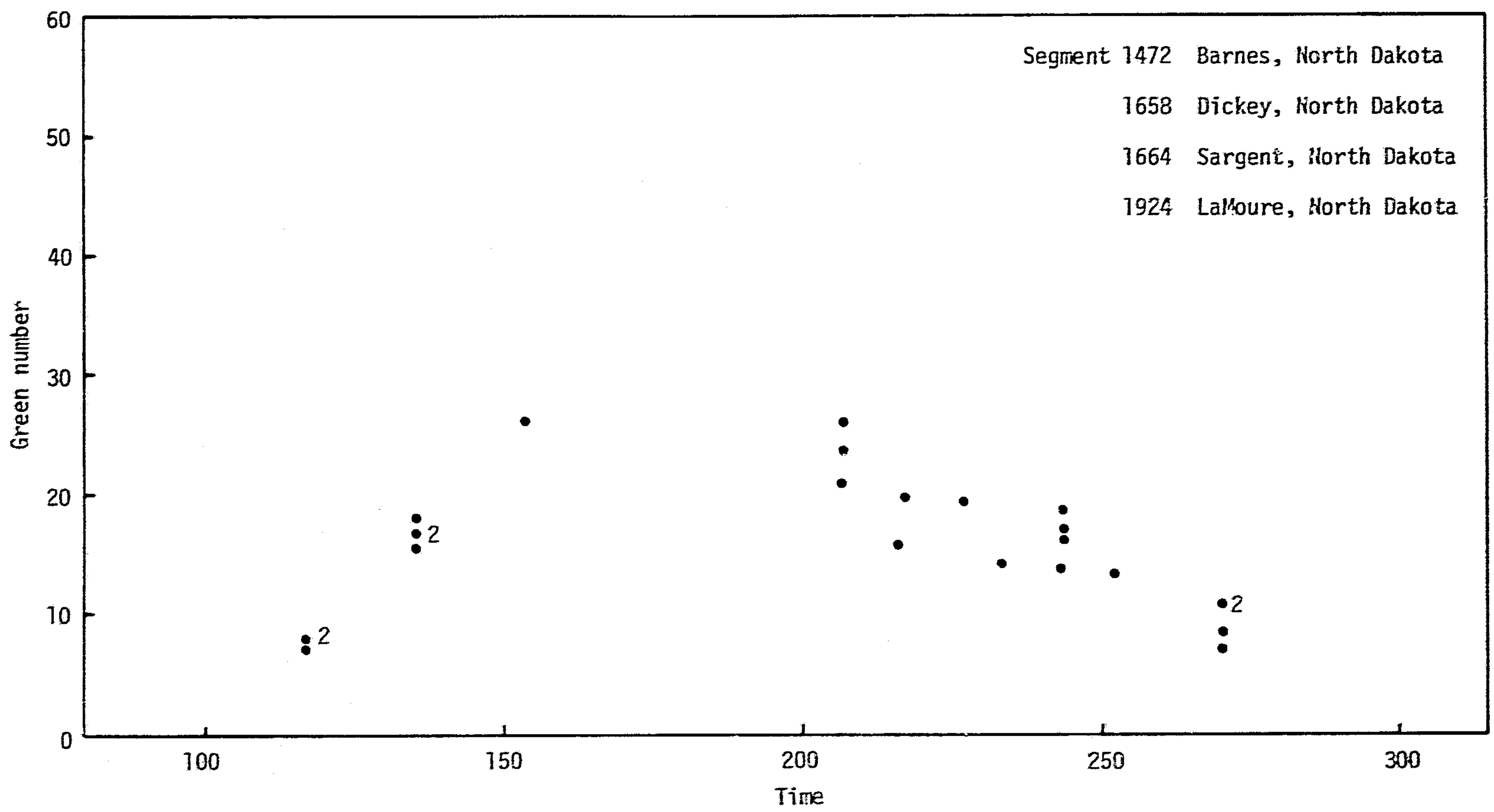

Figure 1a.— Acquisition mean value plot — pasture.

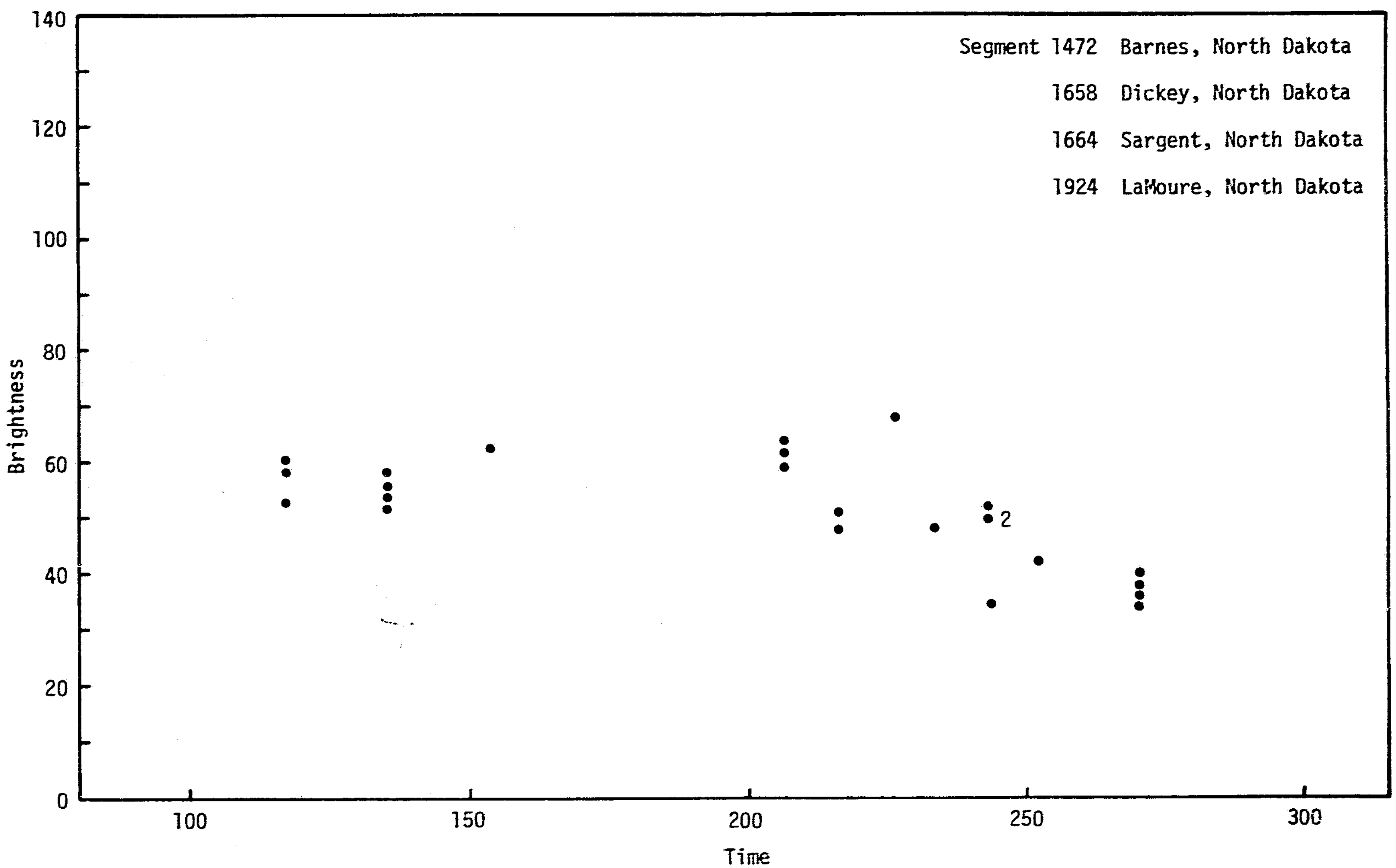

Figure 1b.— Acquisition mean value plot — pasture.

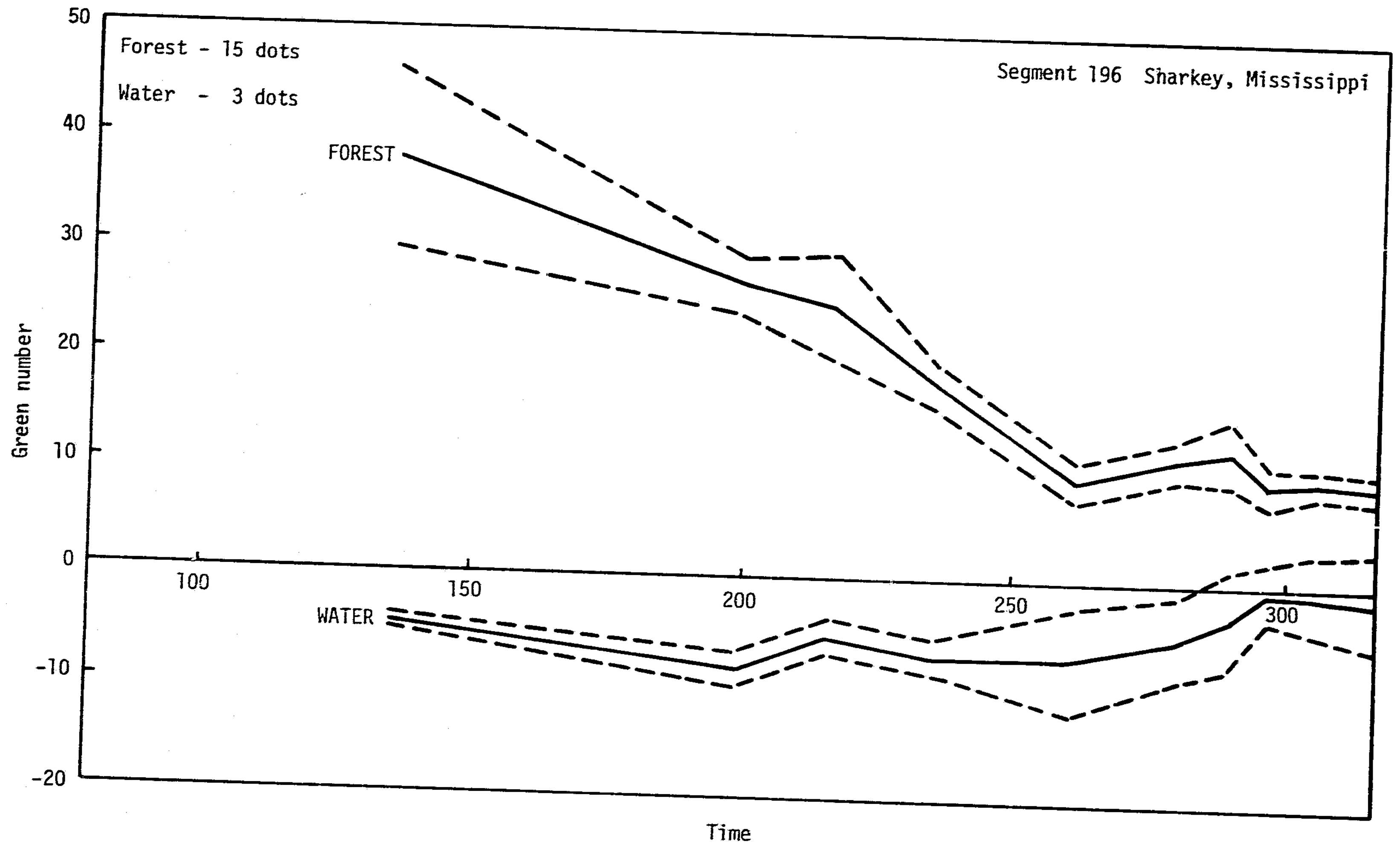

Figure 2a.— Acquisition mean value plot — forest, water.

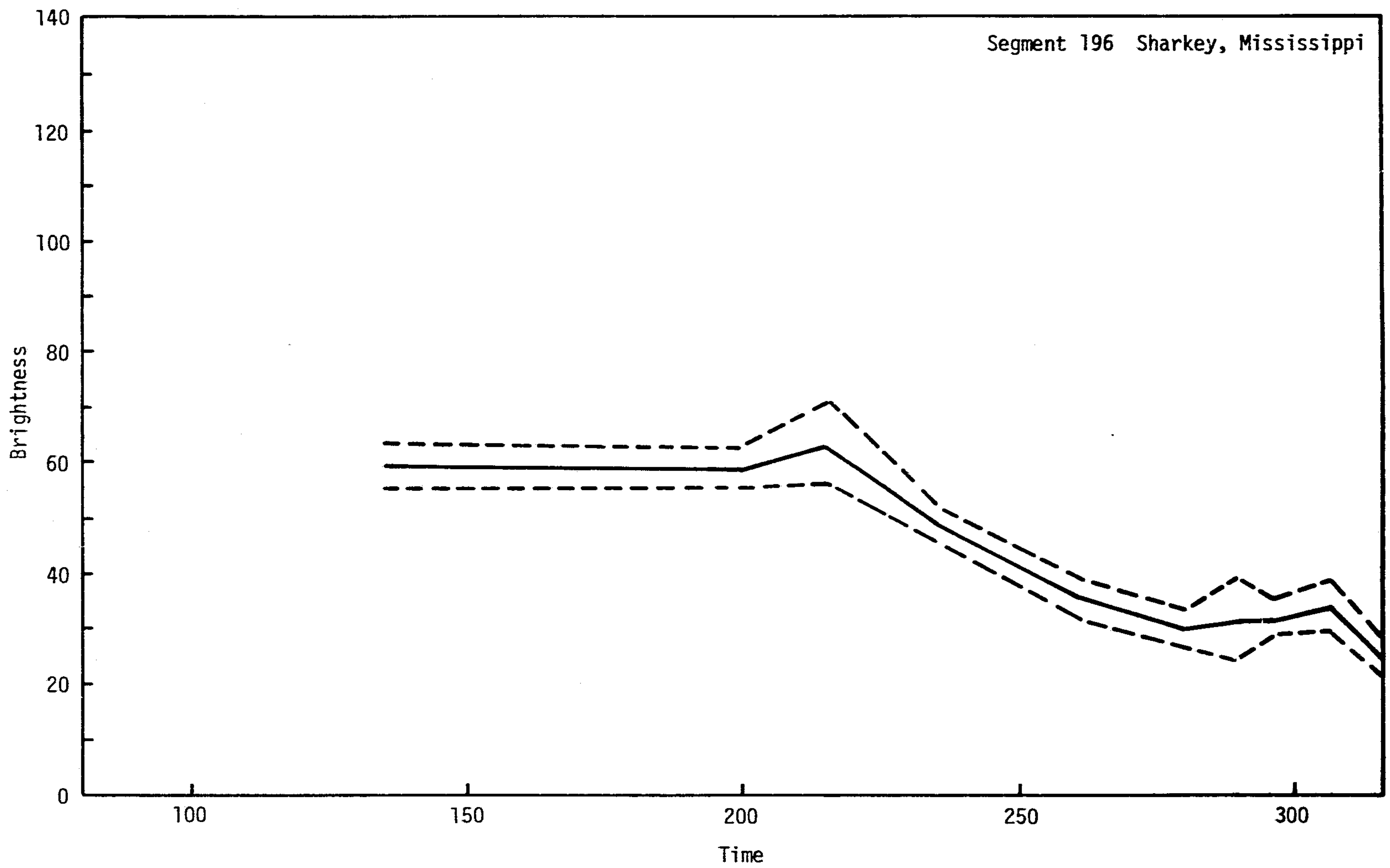

Figure 2b.— Acquisition mean value plot — forest.

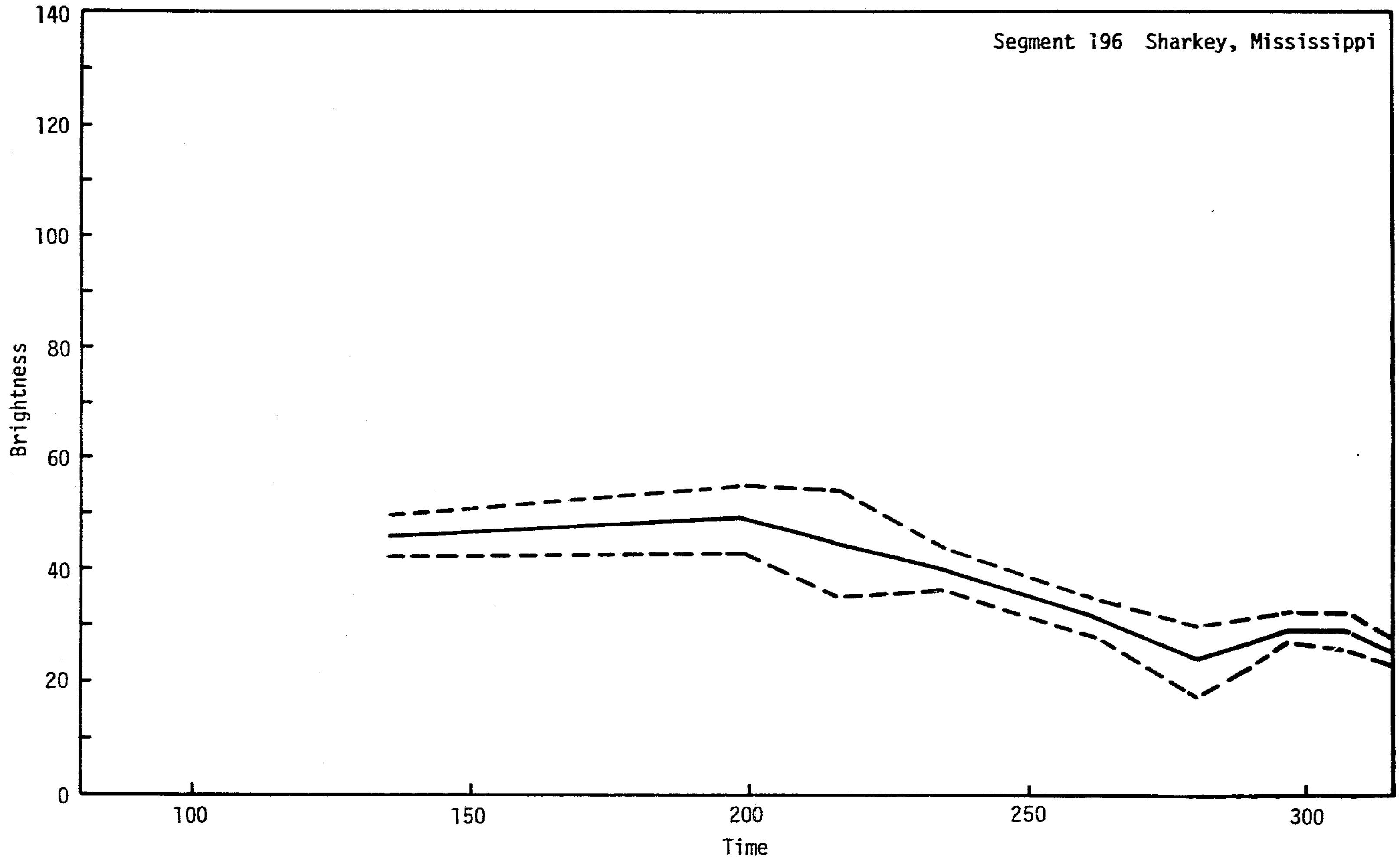

Figure 3.— Acquisition mean value plot — water.

2.1.2 STEP 2 — SEPARATION OF CROPLAND

Many of the labeling discrepancies in step 2 were associated with the definition of the particular biowindow. Each of the biowindows is discussed in relation to the identified problems and the recommended improvements.

Biowindow A, which encompasses preplanting to early emergence, was considered the most troublesome to define. Attempts to shorten the window led to an inability to obtain an acquisition at this critical time of the year. Lengthening the biowindow to encompass earlier acquisitions led to confusion caused by vegetation growing on fields which would later be prepared for corn/soybean planting. To compensate for the labeling inconsistencies related to biowindow A, modifications shown in figure 4 were made to the flow diagram for step 2. The use of spectral aids was incorporated as additional information necessary to eliminate a dot from the summer crop category. The window was moved to the final decision position because the other two windows were more stable and thus more useful in separating nonsummer and summer crops.

Biowindow B is the period when corn and soybeans reach full ground cover. Problems with biowindow B occurred both early and late in the window. Late-planted soybeans often had insufficient vegetative canopy by the early dates in biowindow B and were eliminated as nonsummer crops. Late in the window, corn had sometimes begun to senesce and thus was interpreted as not red. This biowindow can be shortened at both ends to alleviate some of the color-related problems and still be sufficiently long to have a good chance of getting a Landsat acquisition. The separation window will not be changed. As in the Transition Project, it will be used in step 3 processing. A modification was made to the current step 2 flow diagram in figure 4 to further compensate for late-planted and double-cropped soybeans.

Biowindow C, which represents mature to harvested summer crops, was relatively stable but, because of the format of the crop calendars, a closing date for the biowindow was difficult to calculate. Therefore, regrowth vegetation or winter wheat would appear if the acquisition was late in the year. An examination of the corn/soybean test segments showed Julian date 325 to be

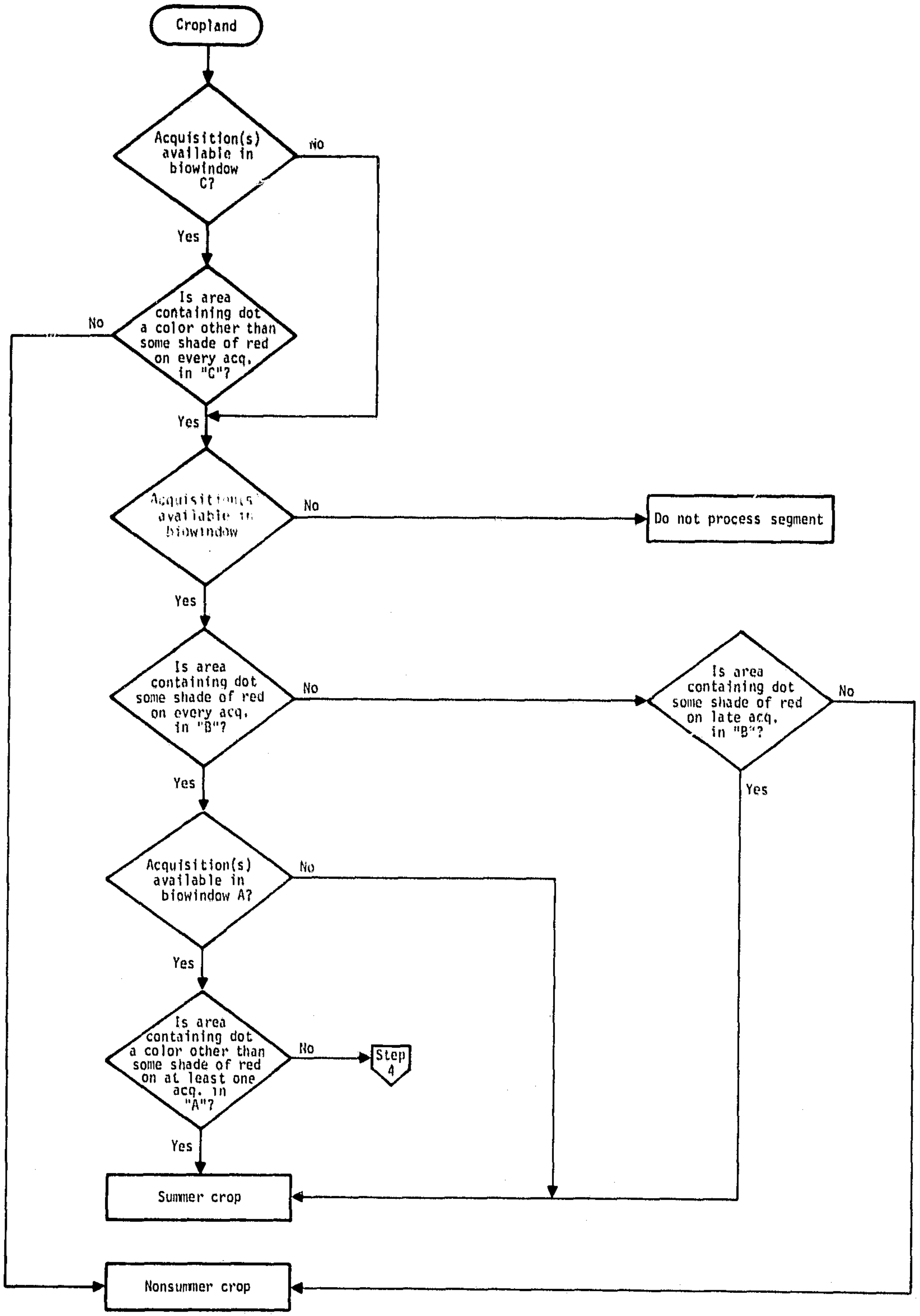

Figure 4.— Revised step 2.

a good date to arbitrarily close the biowindow and leave enough time in which to collect a Landsat acquisition.

Inconsistencies from team to team in defining the biowindows were noted after the corn/soybean exploratory test. Most of the inconsistencies were found when analysts used the bar graph type crop calendars. An alternative to having the team decide on the biowindows was to have all biowindows programed so that they would be defined by a computer and available in the packet at the time of analysis.

The subjectivity of determining shades of color on the film products was a source of error attributed to this step. Automation using a normalized data set was recommended to compensate for film product distortions and to standardize decisions. The development of a normalized data set would require a standard matching of color to numeric data similar to methods being developed (ref. 6).

2.1.3 STEP 3 — IDENTIFICATION OF DEFINITE CORN AND SOYBEANS

The errors in this step show that soybeans were called corn more often than corn was called soybeans. This was explained in the following way: A pixel was not labeled soybeans until it looked significantly different (greener and brighter) from the other summer crop pixels. At this step, more information was needed by the analyst to make a soybean label decision; thus, if proof was not available, then it was a probable corn label. The only significantly consistent problem observed was that late-planted soybeans were labeled corn if an early separation acquisition was used. To remedy this problem, two separation acquisitions will be used in the following manner: If the latest separation acquisition does not have a good break, then the two separation acquisitions should be used to perform the step. Breaks should be defined on both plots, and definite corn and definite soybeans should only be labeled if both plots support it.

The guidelines for determined the breaks and the use of the 5-count limitor were adequate for this step because of the use of the separation acquisition to cover situations occurring within a limited time period.

2.1.4 STEP 4 — IDENTIFICATION OF REMAINING UNLABELED DOTS

Errors were made in step 4 because it was very subjective. The step required the examination of the green number versus time and brightness versus time trajectory plots and labeling of pixels that closely resembled dot trajectories of definite corn or soybeans. The comparisons that had to be made at this step were subjective because of the lack of definable plot profile similarity characteristics. Spectral keys were not developed because there was too much variation between segments. Research should be conducted on methods for reducing between- and within-segment variations. Automation of this step would reduce the subjectivity.

2.2 AUTOMATION REQUIREMENTS

Automation of as many steps in the procedure as possible would enhance the objectivity of the procedure. If any bias remained, it would be more easily traceable and corrective action could be taken. The following flow diagram and comments (fig. 5) identify how such a system could function. The analyst functions are annotated on the left side of figure 5. General requirements are described although it is acknowledged that some of the proposed algorithms, such as the boundary detection and curve-fitting algorithms, are in need of further development. The major concerns in implementing automation of the corn/soybean decision logic are to determine the best vegetative indicator to use for the red/not red discrimination, to select the boundary detection and curve-fitting algorithms, and to develop the software (including the vegetative indicator and the boundary algorithm).

The following information should be available in the output:

1. All good acquisitions, annotated by biowindow and flagged if determined to be the best.
2. Break for each separation acquisition.
3. List of step 3 labeled dots.
4. List of step 4 labeled dots.
5. Confidence of step 4 fit for each step 4 labeled dot.

6. List of pure dots labeled "other."
7. List of step 4 dots labeled "other" for the analyst to label. Time plots should be generated for these dots and a mean and one standard deviation plotted for corn and soybeans as defined by the step 3 labeled dots.
8. List of unlabeled mixed dots.

Step	Requirements	Assumptions	Issues	
Analyst: All good acqs.		(2)		(2) Current procedures
Define biowindows	(1)		(3)	(1) Automated crop calendar program with subroutine of biowindow definitions (3) Only some crop calendars are automated
Sort acqs. according to biowindow	(1)			(1) Program to sort acquisitions
Determine break on sep. acq(s).	(1)			(1) Histogram data for both coordinate axes Break where frequency is lowest Add 5-count limitors Define range for corn and soybeans
Determine best "A" window	(1)	(2)	(3)	(1) Automate search for best acquisition in a biowindow (2) Middle of range is most stable (3) Best acquisition is in middle of biowindow range
Determine best sep. acq.	(1)			(1) Choose acq. w/ the smallest # of dots in decision box. Decision box is the area enclosed by the 5-count limitors.
Determine best "B" window		(2)	(3a) (3b)	(2) Middle of range is most stable (3a) Best acquisition is in middle of biowindow range (3b) Since sep. window overlaps, other than best sep. acq. should be a criterion
Determine best "C" window		(2)	(3)	(2) Earliest acq. is most stable Regrowth may appear on late dates (3) Best acquisition is the earliest

Figure 5.— Corn/soybean automation.

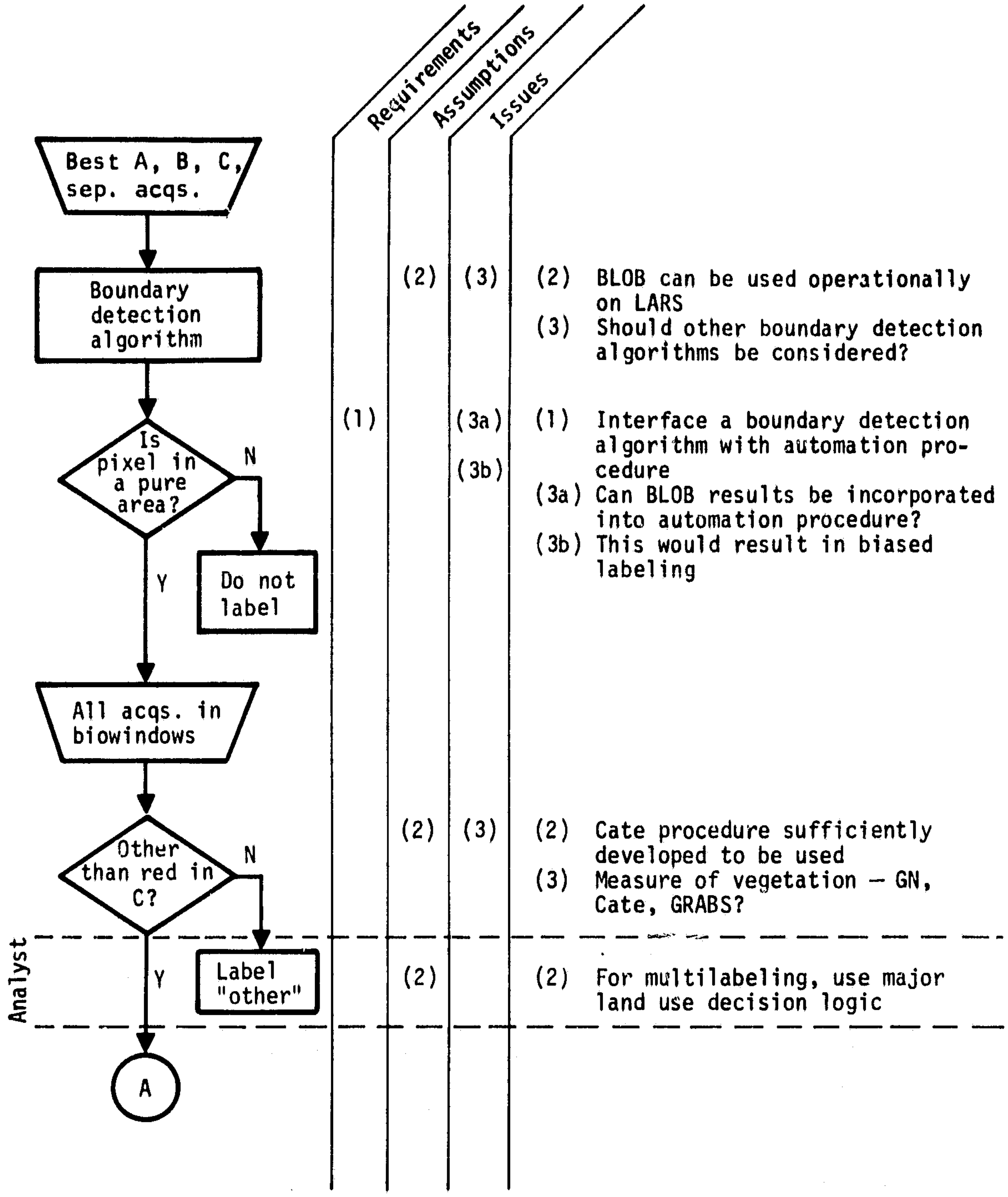

Figure 5.— Continued.

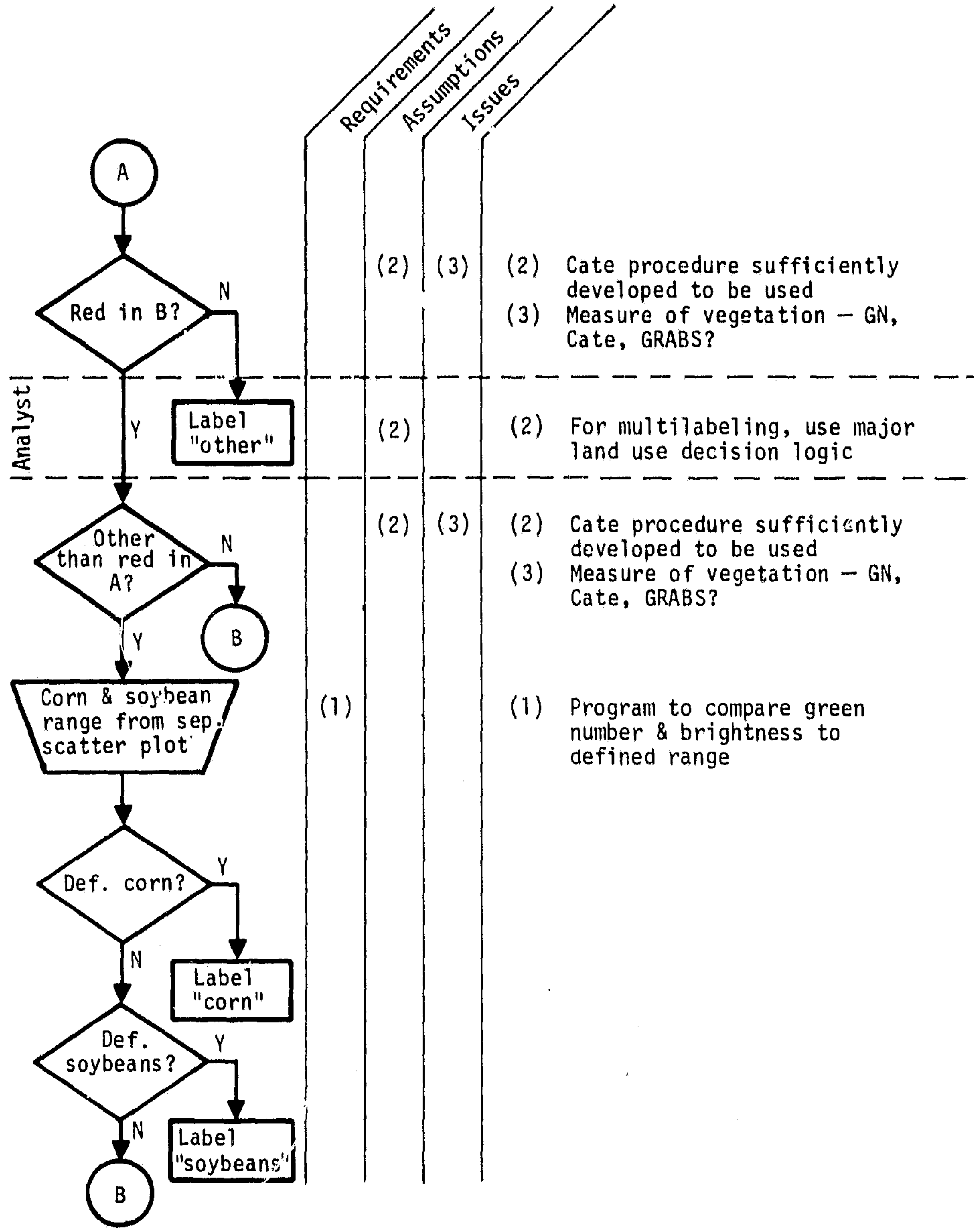

Figure 5.— Continued.

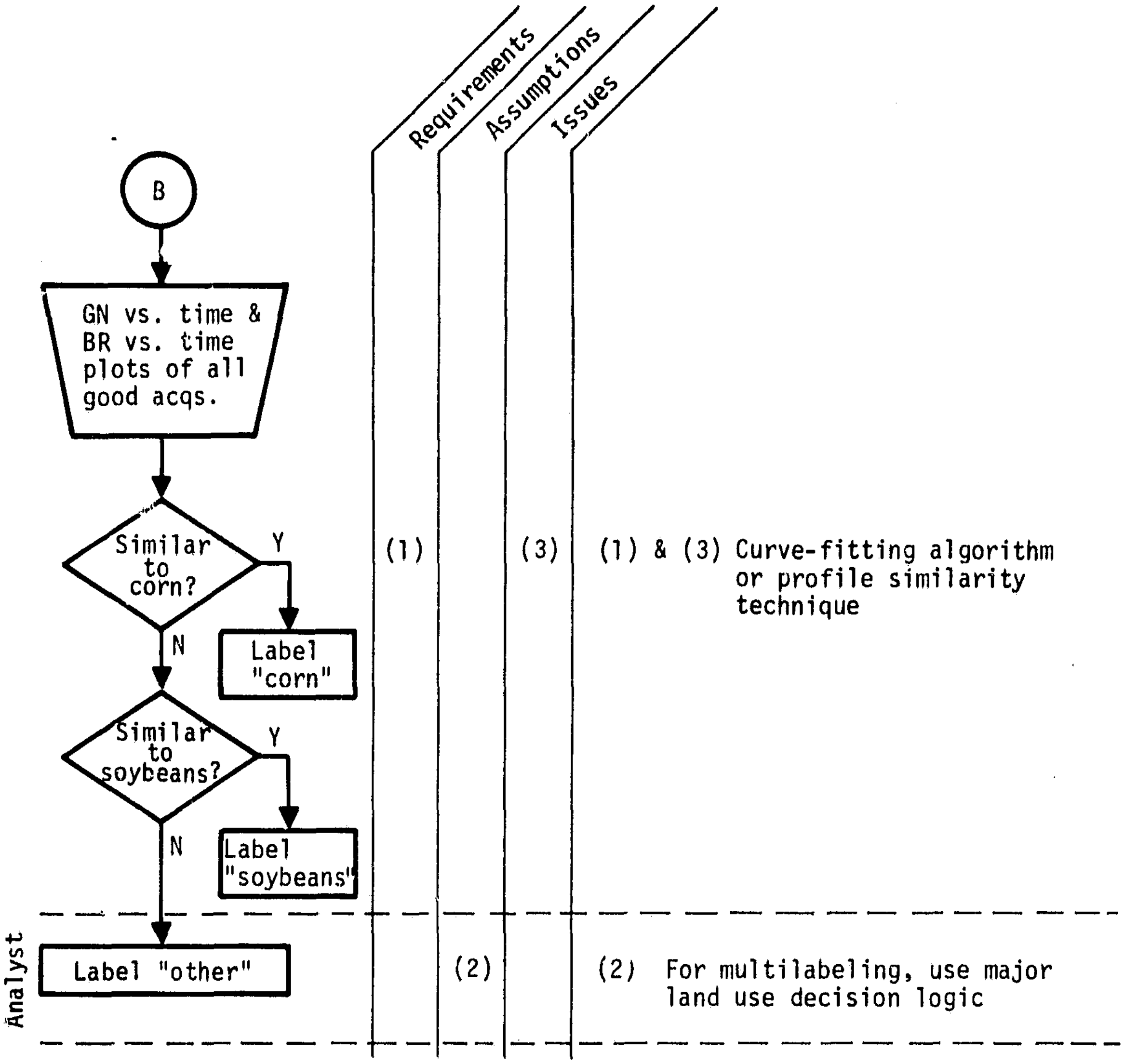

Figure 5.— Concluded.

3. NEW CROPS

3.1 DATA SET

Five segments in North Dakota and one in Minnesota were used to study sunflowers (fig. 6), and four sites in Mississippi and one in Louisiana were available to study cotton and rice (fig. 7). These ground-verified sites were selected so that at least one of the crops, corn or soybeans, was represented on the 209 dot grid. Another criterion for site selection was that the segment should have a fairly good acquisition history as shown in table 2. The North Dakota sites were originally designated for spring wheat and did not cover the entire summer crop growing season. Any information after September 27, 1978, was unavailable for analysis. Minimal 9" x 9" information was available to supplement missing acquisitions for any of the new crop analysis segments.

Normal crop calendars used to identify growth stages for cotton and rice are shown in figure 8a and b. A biostage designation associated with each number on the crop calendar is given in table 3. No attempt was made to develop sunflower crop calendars that could be used at the segment level and none were available. State meterological information for 1978 was compiled for Louisiana, Mississippi, and North Dakota for this study.

Spectral aids were generated for the 209 dots using pure ground truth labels for each segment. For North Dakota sites, the pure dots were designated by analysts using ground truth photography. On all other sites, pure small dots (ref. 18) were used. The products generated included

1. Green number versus brightness scatter plots for each acquisition.*
2. Eight-acquisition green number versus brightness trajectory plots.*
3. Green number versus time and brightness versus time plots for all workable acquisitions.*
4. Mean/standard deviation tables for each major crop in the scene. Both green number and brightness means were generated for each acquisition.

*Operational LACIE-8C products.

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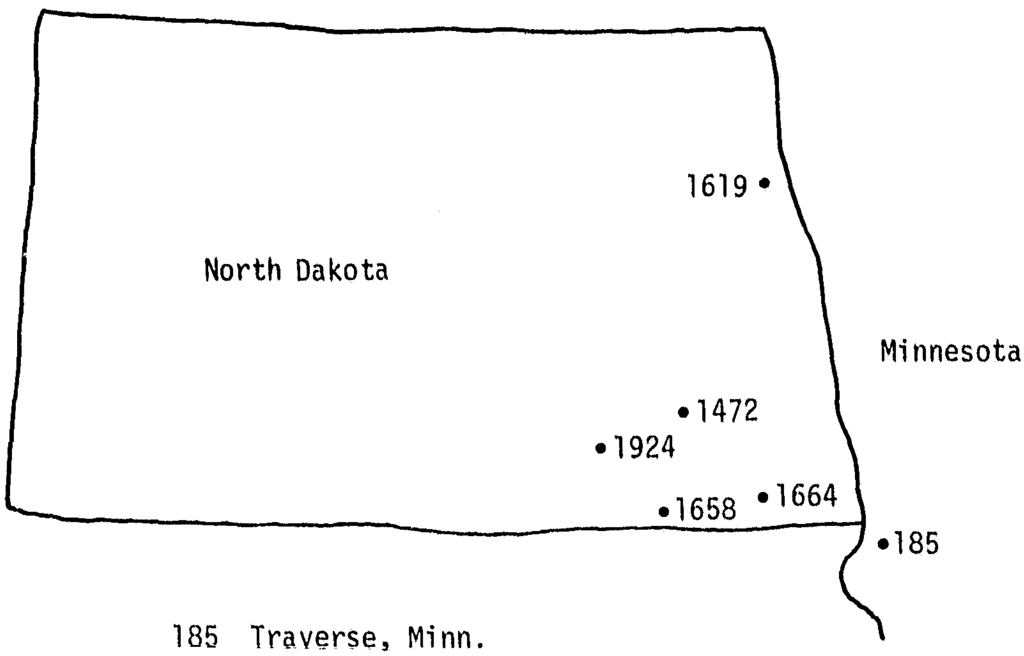


185 Traverse, Minn.

1472 Barnes, N. Dak.

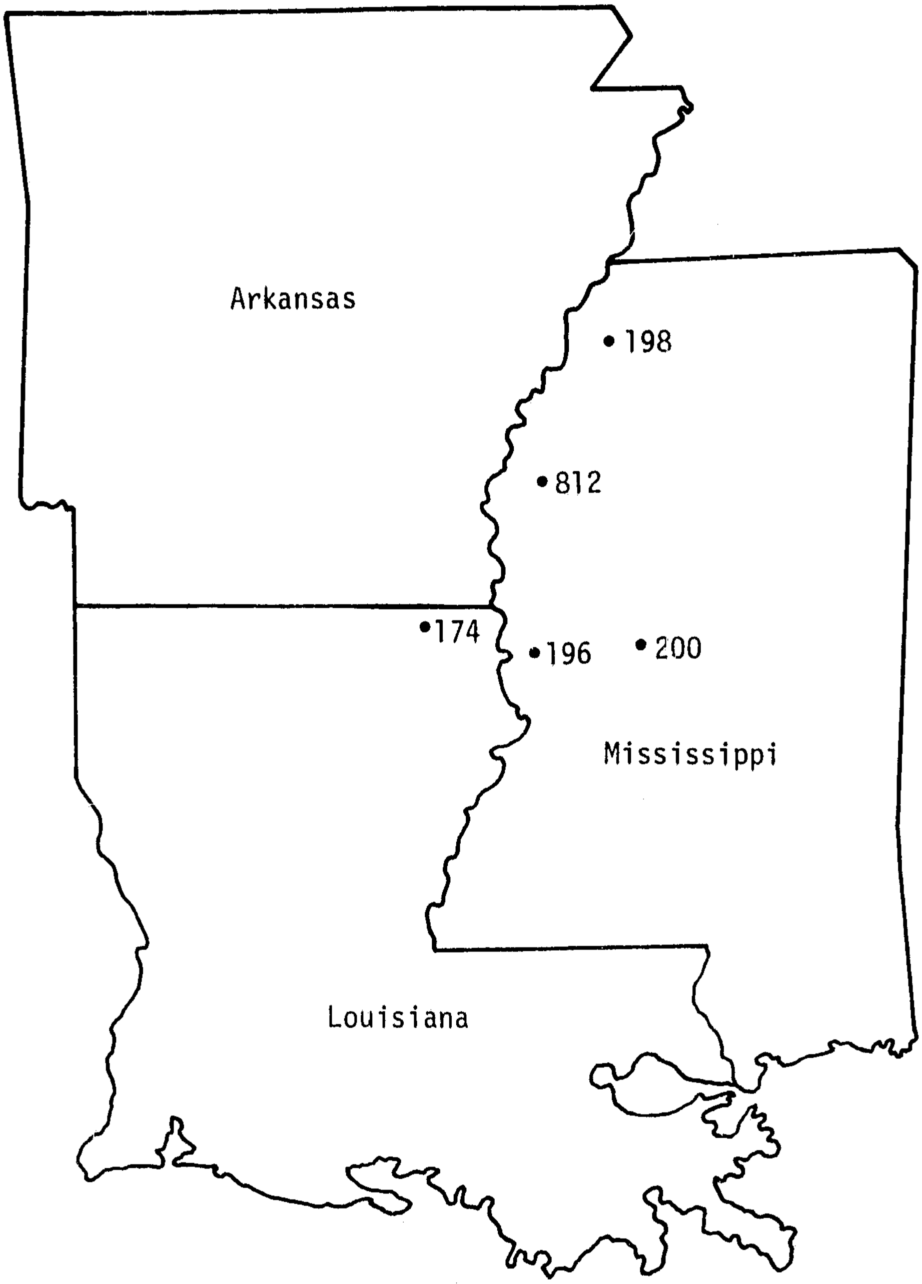
1619 Grand Forks, N. Dak.

1658 Dickey, N. Dak.

1664 Sargent, N. Dak.

1924 LaMoure, N. Dak.

Figure 6.— Sunflower study segment locations



174 Morehouse, La.
196 Sharkey, Miss.
198 Tunica, Miss.
200 Yazoo, Miss.
812 Bolivar, Miss.

Figure 7.— Cotton and rice study segment locations.

TABLE 2.— SEGMENTS USED FOR STUDY

Segment Number	Segment Location	Acquisitions (Julian date – YDDD)
Segments for cotton and rice analysis		
174	Morehouse, La.	8091, 8181, 8199, 8235, 8280, 8289, 8307
196	Sharkey, Miss.	8135, 8181, 8199, 8207, 8216, 8235, 8243, 8262, 8280, 8289, 8297, 8306, 8316, 8351, 8360
198	Tunica, Miss.	8126, 8135, 8180, 8199, 8207, 8235, 8262, 8279, 8289, 8297, 8307, 8351, 8360
200	Yazoo, Miss.	8135, 8207, 8216, 8234, 8279, 8297, 8306, 8351
812	Bolivar, Miss.	8091, 8181, 8199, 8207, 8226, 8235, 8280, 8289, 8307, 8316
Segments for sunflower analysis		
185	Traverse, Minn.	8089, 8133, 8169, 8197, 8205, 8214, 8224, 8232, 8241, 8250, 8287, 8296, 8305
1472	Barnes, N. Dak.	8117, 8135, 8216, 8243, 8252, 8270
1619	Grand Forks, N. Dak.	8135, 8198, 8207, 8216, 8243, 8252, 8270
1658	Dickey, N. Dak.	8117, 8135, 8207, 8243, 8252, 8270
1664	Sargent, N. Dak.	8117, 8134, 8135, 8206, 8233, 8243, 8269, 8270
1924	LaMoure, N. Dak.	8135, 8136, 8154, 8198, 8207, 8208, 8216, 8217, 8226, 8243, 8252, 8270

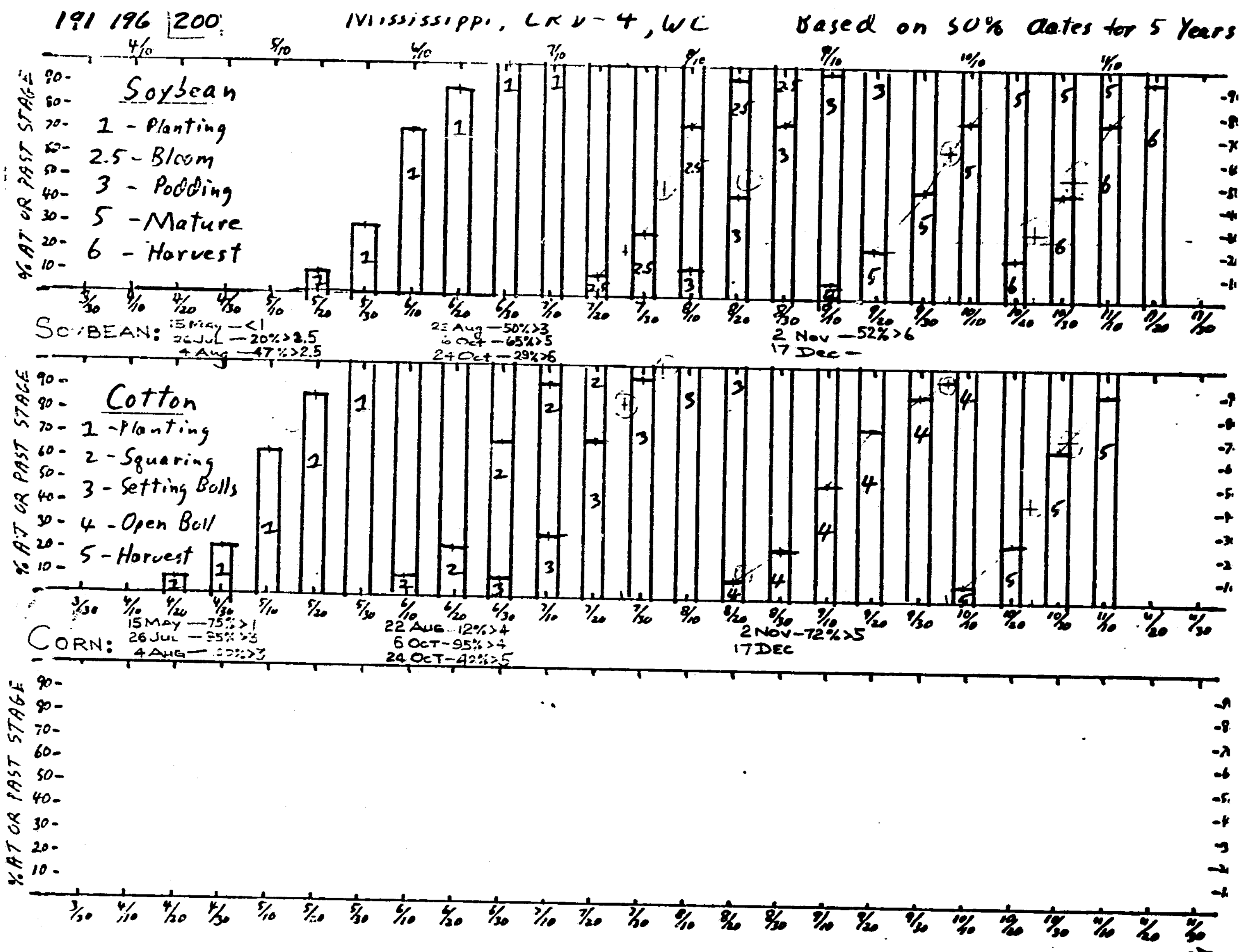


Figure 8a.— Crop calendar for cotton and rice.

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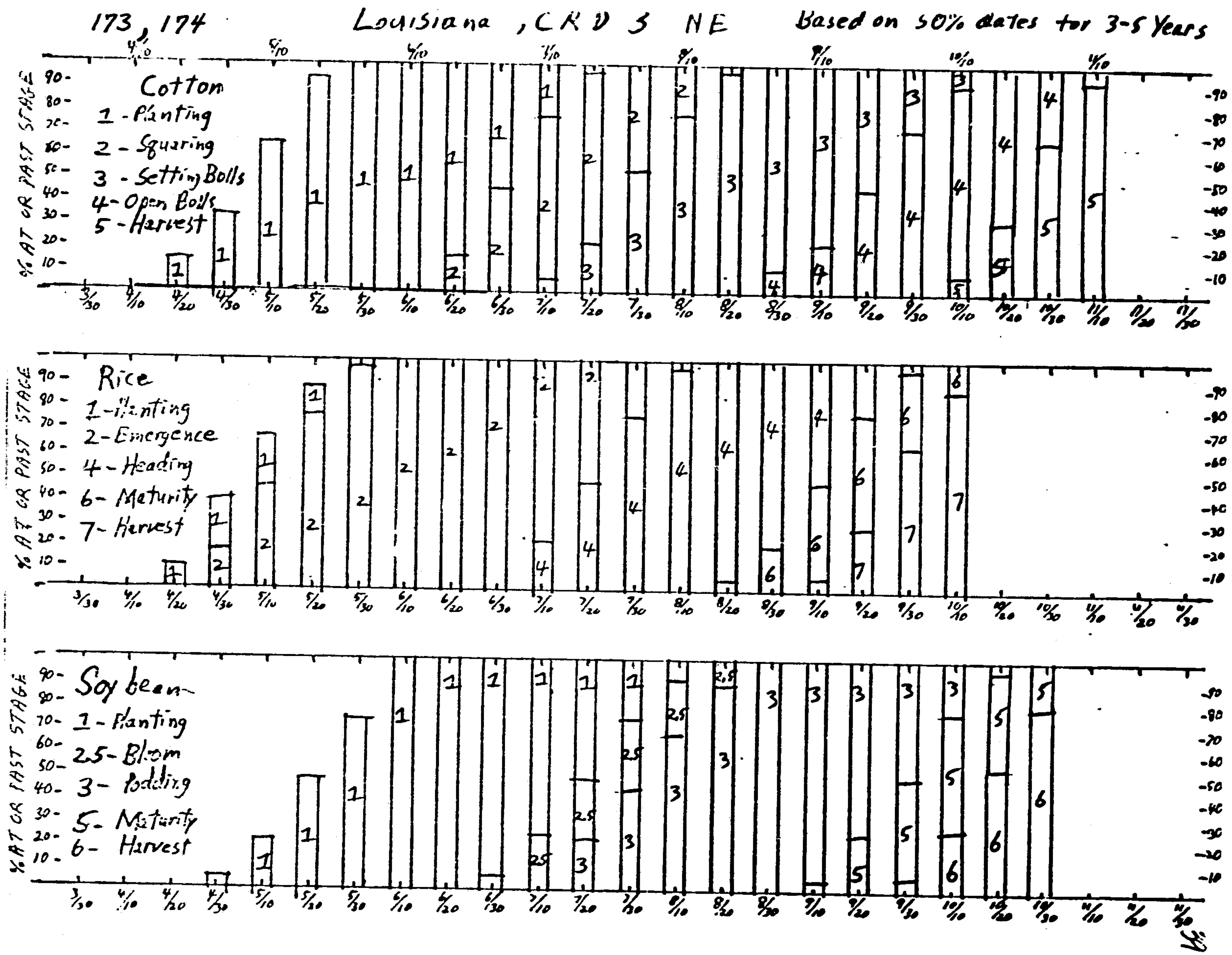

Figure 8b.— Crop calendar for cotton and rice.

TABLE 3.– CROP GROWTH STAGES

Growth stage number	Corn growth stage	Soybean growth stage	Rice growth stage	Cotton growth stage	Sunflower growth stage
1.0	Planting	Planting	Planting	Planting	Planting
2.0	Floral initiation	Rapid nodal development	Emergence	Squaring	Emergence
3.0	Tassel-silk	Full podding	Jointing	Boll setting	Heading
4.0	Denting	Full seed	Heading	Open boll	First anther
5.0	Maturity	Maturity	Turning	Harvest	Last anther
6.0	Harvest	Harvest	Mature/ripe		Maturity
7.0			Harvest		Harvest

Crop stages from the historical crop calendars, image characteristics from product 1 and product 3, and the mean values for green number and brightness are summarized in appendixes B and C. This information will be discussed later in this report.

3.2 APPROACH

Since the analysts had little or no exposure to the characteristics of the new crops, an information search was the first task undertaken. Literature explaining plant physiology, crop stages, planting regions, and cropping practices was reviewed. A synopsis of the information that can be used in image analysis appears in the discussion of each crop and its characteristics.

Crop stage information was gathered (when available) in relation to the crop's appearance on the Landsat imagery. Both product 1 and product 3 were analyzed for signature variability and usefulness.

Current LACIE-8C (ref. 10) spectral aids using ground truth pure dots were examined for trends and usability. The mean/standard deviation information was plotted and used for crop-to-crop and segment-to-segment comparisons.

3.3 COTTON AND RICE

3.3.1 RICE CHARACTERISTICS AND CROPPING PRACTICES (refs. 8, 9, 12, 16)

Rice is one of the great cereal plants grown in the world. Over half the world's population subsists wholly or partially on rice. Rice became an important crop in the United States when cultivation was made profitable by mechanization. The commercial rice crops of the United States are grown almost entirely in Arkansas, California, Louisiana, and Texas. Recently, improved varieties have been developed that significantly increase production.

Rice flourishes under widely differing climatic conditions. Although rice is generally suited to wet tropics, it is also grown in temperate and arid regions.

Cultivation of rice tends to be concentrated in regions where there are flat lowlands, river basins, and deltas because of the water requirements of the plant. Alluvial soils, which consist of young marine and river deposits, occupy the major part of the wetland rice areas. The semi-aquatic conditions under which rice is cultivated necessitate a heavy soil through which irrigation water will not easily percolate. Rice grows better on heavy, dark clay soils than on lighter, sandy soils.

Rice is a cultivated branching grass widely grown as a dryland crop but more commonly grown in water. The genus of rice contains both annual and perennial species. The cultivated forms are generally grown as annuals and behave as such when drought or cold brings the plant's life to an end. Rice is capable of producing more than one crop annually, and, where moisture and temperature permit, regrowth occurs after the first harvest.

The majority of commercial rice varieties, ranging from 3 to 7 feet in height, can be characterized as an annual grass with round, hollow, jointed culms; rather flat, elongated leaf blades; and a terminal panicle or head.

The biostages of rice begin with the planting of the seed and the initial germination of the grain. The early emergence and first leaf formation constitute the second phase. The tillering stage starts with the appearance of the first tillers and continues until joints appear along the stalk. The heading stage occurs when the grain head has emerged from the leaf sheath. As the grains ripen, the leaves become senescent and turn yellowish in an ascending order in the turning stage of development. The mature or ripe stage occurs when all the grains are fully ripe. Harvest occurs when the grain is combined. New tillers may grow from the stubble of the harvested plants with subsequent harvests.

Rice cropping practices in the United States vary locally but follow the same general pattern. To allow flooding of the rice field, bunds or levees are constructed along contour lines during winter so that the ground can settle before irrigation begins. The land is usually ploughed either in the autumn or in the spring and prepared for seeding in spring. Rice seed is

planted using seeders or drills on dry fields, while aerial broadcasting is used over flooded fields. Irrigation begins when the plant reaches a height of about 6 to 8 inches. The crop is submerged to a depth of 1 to 2 inches. Irrigation helps control weeds, along with supplying nutrients to the rice. Water is held on the land until the heads turn down and begin to show early signs of ripening; then the field is drained and dried to allow the use of heavy machinery for harvesting. Harvesting is usually done with a combined harvester-thresher that cuts the rice; strips the grain from the stalk; then separates the grain from the straw, weed seeds, chaff, dirt, and other foreign matter.

3.3.2 COTTON CHARACTERISTICS AND CROPPING PRACTICES (refs. 3, 9, 12, 17)

Cotton, derived from the seed hair of several species, is the most important vegetable fiber in the world today. Cotton growing requires a long frost-free season, moderately abundant moisture, and either extensive mechanization or ample cheap labor. Cotton is often grown under irrigation in semi-arid and arid environments. Production of cotton in the United States is shifting from the South to land west of the Mississippi.

Cotton is generally planted on fine-textured soils that are characteristically well drained. Alluvial soils that are well drained occurring in flood plains or bottomlands are among the most productive for cotton. Planting cotton on variable soils causes variations in crop growth.

Commercial cotton species are perennial but are usually grown as annuals in North America. The plant normally develops to a height of about 3 to 4 feet. As the cotton plant grows, it produces many side branches which bear large flowers progressively from the base outward. Seed capsules, called bolls, mature from the flowers. Maturity occurs when the bolls split, revealing many seeds, each with its mass of cellulosic seed hairs or fibers.

Cotton is a crop grown in the summer in North America. Planting may be staggered from March to June to avoid a seasonal glut at harvest. Planted rows are usually mechanically thinned as the cotton sprouts to assure only one plant every few inches. Weeds are usually controlled by herbicides.

Cotton is planted in either solid-row or skip-row patterns. Solid-row planting is the common planting practice in the United States although skip-row planting patterns are becoming more prevalent. Skip-row planting patterns vary from planting two rows and skipping one to planting four rows and skipping four.

Cotton development phases are consistent, following an orderly time schedule, but they can vary with variety, temperature, soil moisture and fertility, length of growing season, insects, diseases, and cultural methods. Emergence can occur as early as 4 days after planting or under adverse conditions as late as 3 to 4 weeks. Appearance of the first floral bud usually occurs about 40 days after seedling emergence. Development of the floral bud into open bloom is the next biostage. Appearance of blooms after the first bloom usually requires 3 days for each bloom. Boll development from open bloom to splitting of the boll varies from 40 to 80 days because of temperature variation. Boll shedding is affected by internal conditions of the plant and precedes harvest.

Chemical defoliants are used before harvest to free the plants of interfering foliage. Harvest is completely mechanized with a cotton picker going over the field twice. After the picker finishes in the field, a scrapper strips the plants of any fiber left on the plant.

Crop rotations are less common on cotton farms than on farms where a more general type of farming is practiced. Sugar cane and rice occupy land generally unsuitable for cotton. Crops used in rotations with cotton include legumes and corn.

3.3.3 ANALYSIS AND CONCLUSIONS

The analysis of the cotton/rice color signatures presented in appendix B indicated early spring planting of rice, a strong red signature midsummer, then harvest early in the fall (mid-September to mid-October). No water signatures were seen as had been expected, but this was due to a lack of

early acquisitions. Cotton is planted slightly later than rice; it greens up later in the summer but never has as green a response as rice. Even at maximum canopy, cotton still appears as a mottled red signature, probably because of cultivation practices allowing the soil background to dominate. Cotton has a harvested signature in mid-November to mid-December. Generally, soybeans appear on the imagery to be planted the latest of the three crops; however, soybeans were observed being planted both early and late compared to the other crops. Soybeans appear red on the imagery later in the summer than rice or cotton. The soybean crop has a mottled red or brown turning signature in October to early November. Soybeans harvest signatures appeared in mid-November.

Soybeans were found to have different curve characteristics in the Southern States than in the Corn Belt. The soybean curves were variable. Some looked like the classic Corn Belt curve, but others were completely different, as is shown in figures 9 and 10.

Analysis of the pure dots on the scatter plots showed that spring crops could be distinguished from summer crops. The spring crops formed a cluster along the green arm of the plot in late spring and early summer while the summer crops clustered near the soil line. On August acquisitions, the reverse pattern was seen, with spring crops near the soil line and summer crops high on the green arm. Rice was separable from cotton and soybeans from mid-June to mid-July. Later in the growing season, rice remained mixed with the other crops on the scatter plot. Cotton consistently had a higher brightness value in relation to other crops in the segment throughout the growing season.

Green number means (appendix B) and standard deviations of pure dots for each crop for each acquisition were useful in facilitating crop-to-crop and segment-to-segment comparisons. Certain trends for each crop were identified or substantiated by using plots such as those shown in figure 11. The green number for rice increases more rapidly and attains a high level sooner than the green number for either cotton or soybeans. Rice will start to decrease in green number sooner than cotton or soybeans. Cotton's green number peaks

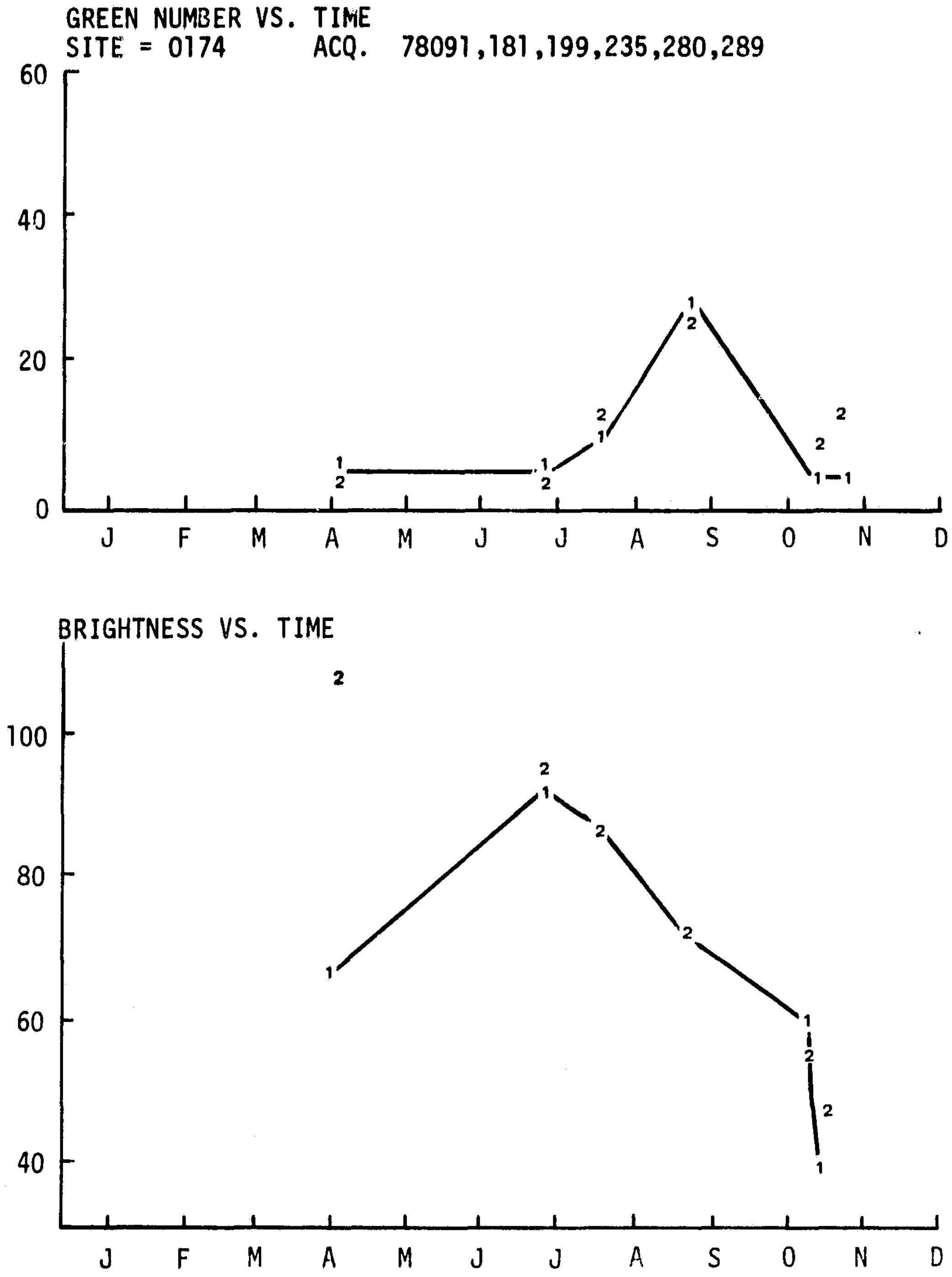

Figure 9.— Normal soybean time plot — Louisiana.

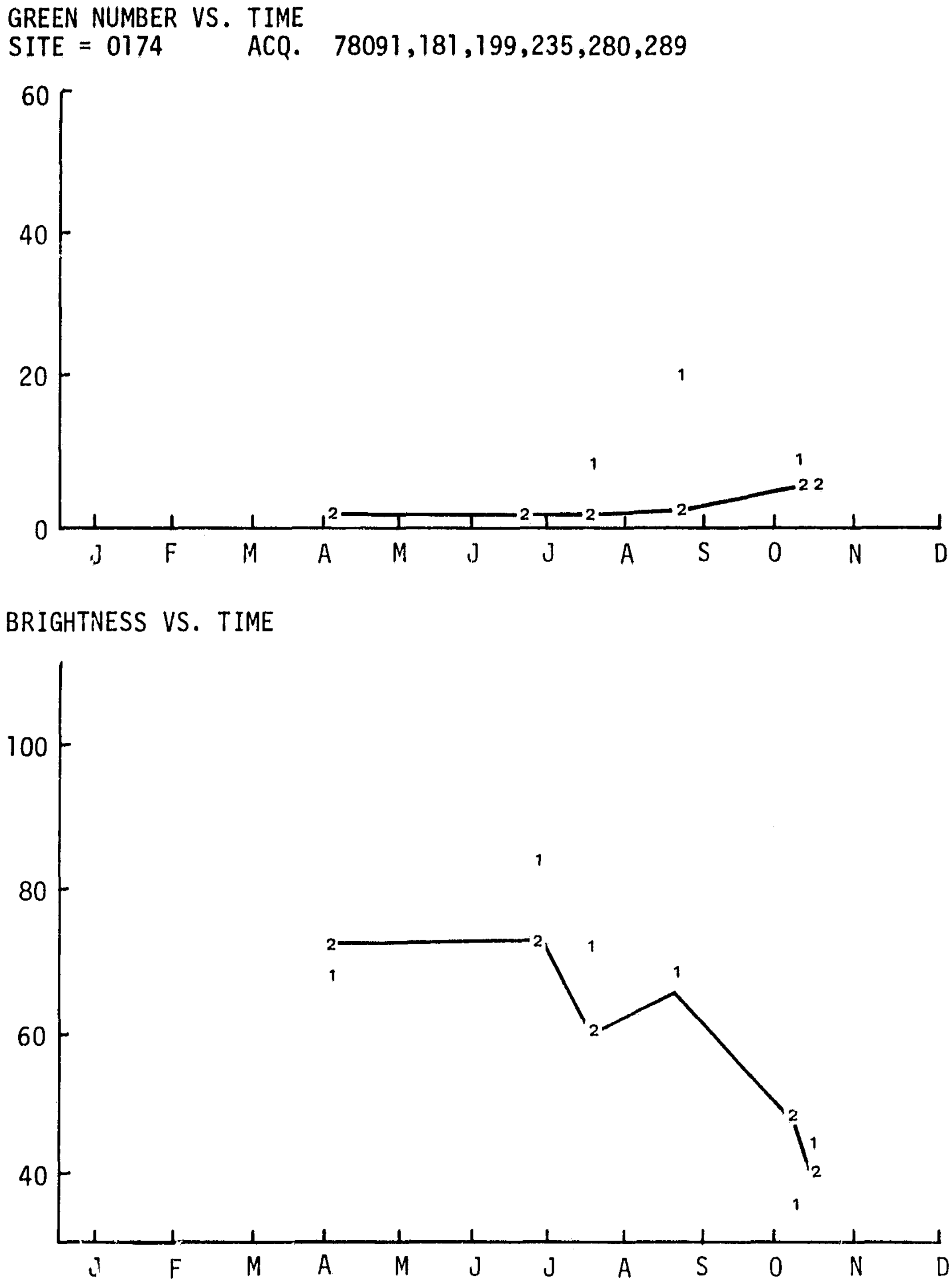

Figure 10.— Abnormal soybean time plot — Louisiana.

about the same time as soybeans' and at approximately the same height as that for soybeans. The cotton green number decreases at the same rate as does the soybean green number. The green number for soybeans is higher than that for rice later in the year and higher than that for cotton for a longer time.

The mean brightnesses for rice, cotton, and soybeans are given in appendix B and figure 12. Rice brightness increases around mid-May and maintains a stable level until the last of August, when a gradual decrease begins. The rice brightness never attains the high level of cotton but is similar to soybean brightness. Cotton brightness levels are higher than those for either rice or soybeans throughout the crop growth cycle. Soybeans' brightness is more variable than that for other crops. Some soybeans are intermingled with cotton on the latter part of the acquisition history thus causing confusion between soybeans and cotton.

The brightness difference between cotton and soybeans was further investigated at the dot level. The means for cotton pure dots and for soybean pure dots were calculated and cotton was compared to soybeans. Almost all the cotton dots had a higher brightness over time than soybeans on a given segment. Very little overlap existed. The brightness values were not consistent from segment to segment. In one segment, cotton dot brightness means would average in the 60's and those for soybeans in the 50's and, in the next segment, cotton dot brightness values would be in the 70's and those for soybeans in the 60's. Therefore, no arbitrary brightness number was found to identify cotton.

3.4 SUNFLOWERS

3.1.1 SUNFLOWER CHARACTERISTICS AND CROPPING PRACTICES (refs. 5, 9, 12)

Sunflowers are native to the U.S.A. and can be considered either a weed or a cultivated crop. In the United States, the crop is grown for both food and oil. The oil, however, is more important in world trade considerations. The crop is grown mainly between latitudes of 30 to 50 degrees, with the largest concentrations located in North Dakota, South Dakota, Minnesota, and Texas. Recent advances in hybrid varieties, which have a high oil content, have made

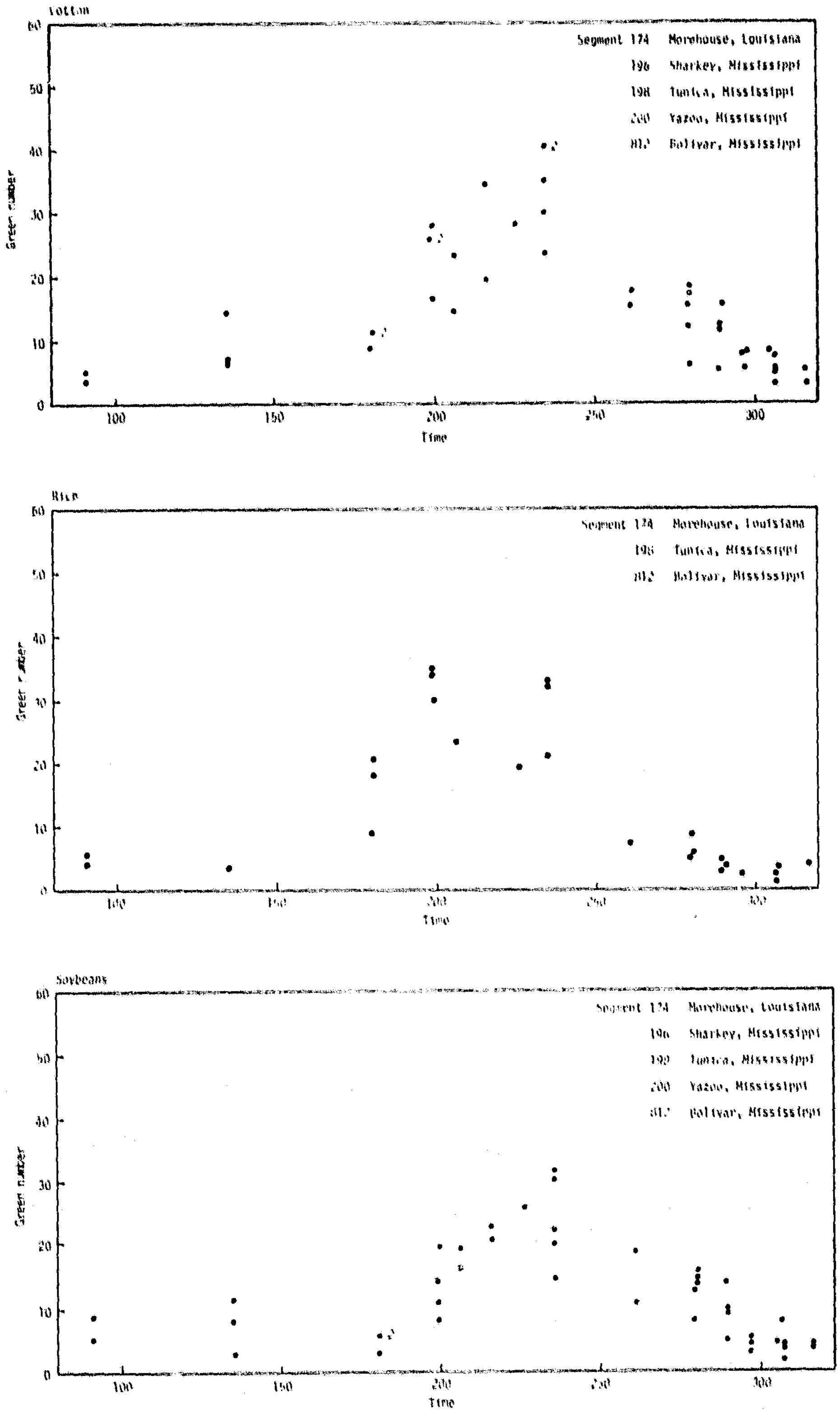

Figure 11.— Acquisition mean value plots for cotton, rice, and soybeans.

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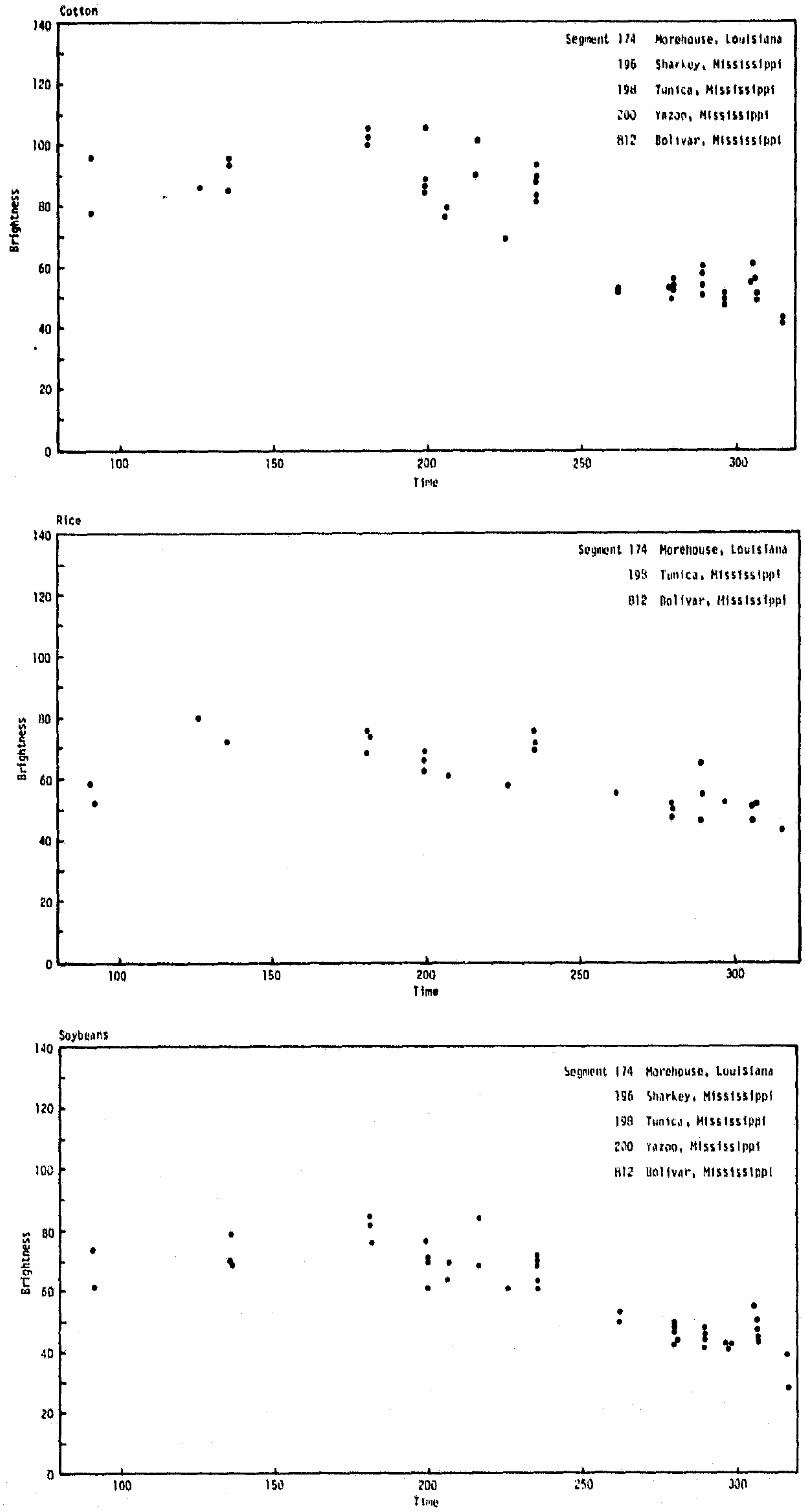


Figure 12.– Acquisition mean value plots for cotton, rice, and soybeans.

sunflower production a profitable investment. Sunflower production in the U.S.A. has increased rapidly, in North Dakota alone, from 25 732 acres in 1959 to over 1.5 millon acres in 1978.

Sunflowers are a 120-day crop which can be grown in soils with a texture from sandy to clay. Sunflowers are generally considered a dryland crop but may be irrigated in areas where severe soil moisture shortages affect plant production. Sunflowers are not particularly drought resistant but are tolerant to both cold and hot weather, which makes them so adaptable to different latitudes. Generally a single crop, sunflowers may appear as a second crop in areas with a long growing season (e.g., Mississippi, Louisiana). The trend is for sunflowers to replace cotton and flax, while future expansion of sunflowers into the fringes of the present corn, soybean, and cotton growing areas is expected.

Sunflowers are planted from late April to late May in the northern United States and from the middle of March to the end of April in the southern United States. Commercially grown sunflowers are generally planted according to tillage methods in the local area so as to be compatible with available equipment. The cultivated varieties generally have one main stem, 4 to 20 feet tall, although some branching varieties are known to be grown commercially. The leaves, which range in color from light green to dark green, vary in size and shape and are in a spiral arrangement around the main stem. The sunflower is heliotropic, which means that the plant follows the sun. This occurs until the plant flowers. After flowering, the heads usually remain tilted to the east. Farmers often take advantage of this phenomenon and plant sunflowers in north-south rows to make heads easily assessible at harvesting. The sunflower produces a large head consisting of a disk of a thousand or more individual flowers, on a receptacle surrounded by yellow ray flowers backed by bracts which are an extension of the leaf system. The plant is mature when the back of the head turns yellow. The sunflower crop is harvested using modified corn or soybean harvesting equipment.

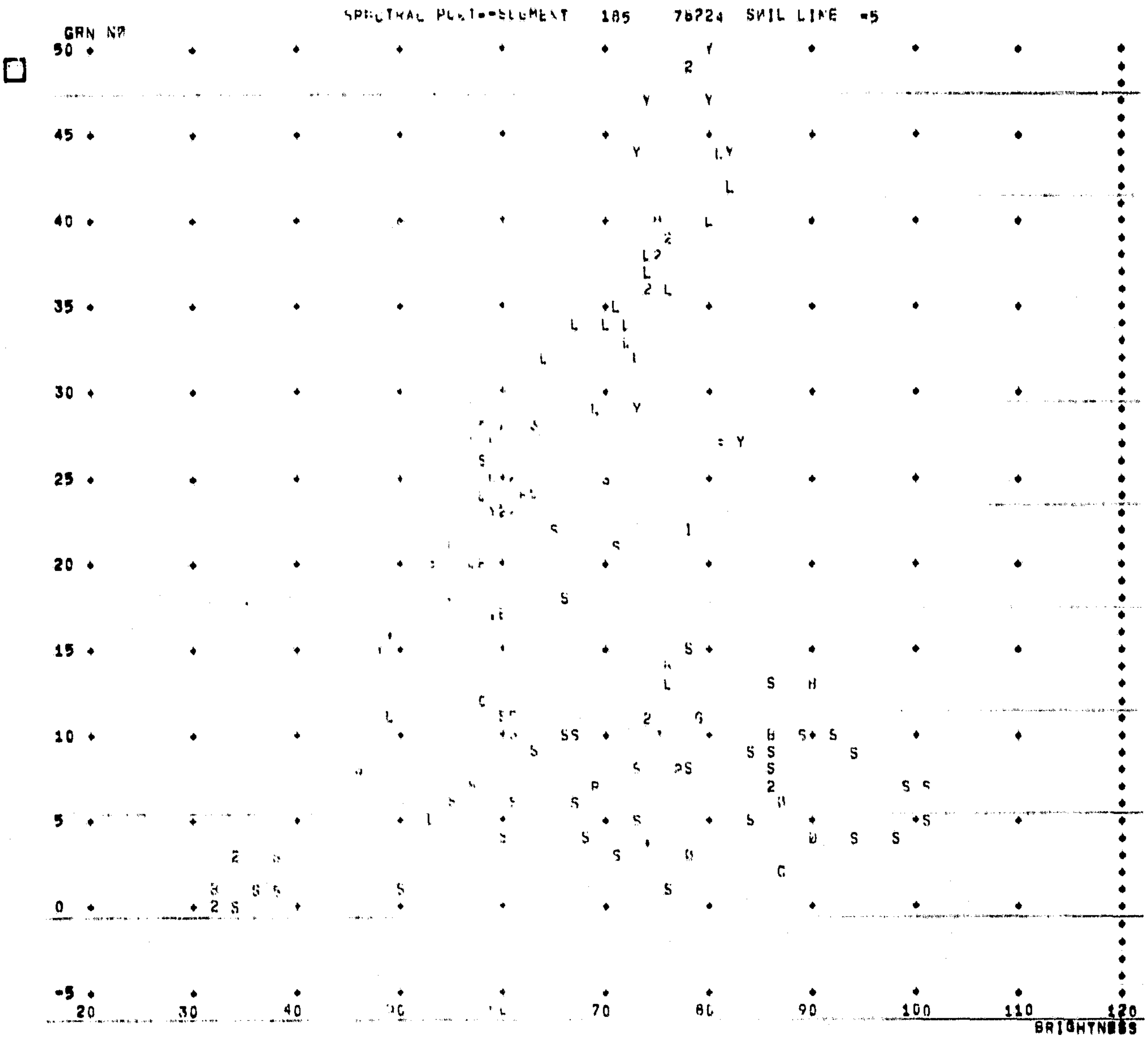
3.4.2 ANALYSIS AND CONCLUSIONS

Analysis of sunflower signatures on the Landsat imagery showed that the crop color was variable. Appendix C gives the color of sunflowers and other major crop signatures for each acquisition in each segment. Red signatures for the emerging crop appear in early to mid-July. The sunflower fields were either a bright red or a dull red throughout the summer. The dull-colored sunflowers look similar to corn throughout the growing season and are considered a confusion crop. In most cases, the bright red sunflowers can be distinguished from other summer crops, such as soybeans, sugar beets, or potatoes, on a series of acquisitions, but the signatures might be confused on a single acquisition. In Minnesota (segment 185), in September sunflowers had a purplish signature on product 1, but this distinctive signature was not observed on any of the North Dakota sites. Sunflowers and corn senesce at approximately the same time. On segment 185, harvested corn fields had a white signature while sunflower fields were dark. Unfortunately, this difference could not be further investigated because of lack of harvest acquisitions of the North Dakota segments.

Because of the out-of-phase growth cycles, no confusion existed between the spring crops and summer crops. Spring crops generally had a full vegetation canopy (red) when summer crops were being planted (green, gray), and virtually all spring crops had mature signatures (green, gray, yellow) when summer crops reached full vegetative canopy (red, bright red).

No effort was made to associate colors with crop stages because the crop stage information for sunflowers is not clearly defined currently.

The examination of the LACIE-8C (ref. 10) spectral aids confirmed what was seen on the imagery. Sunflowers are spectrally mixed with other summer crops throughout the growing season on the scatter plots. In segment 185, the sunflowers did form a brighter cluster along the green arm than corn or soybeans on the August 12 scatter plot shown in figure 13, but this phenomenon was not seen on other segments. No distinctive patterns for sunflowers could be identified using either the time plots or the trajectory plots.



<u>Legend</u>

A	Alfalfa	M	Sugar beets
B	Barley	Ø	Oats
C	Corn	P	Pasture
G	Grains	S	Spring wheat
I	Idle	Y	Soybeans
L	Sunflowers		

Figure 13.— Spectral plot showing summer crops with sunflower cluster.

The green number means for corn and sunflowers are shown in figure 14. Both crops green up starting in June and reach their peak at the end of July or in early August. Corn begins to decline at a slightly faster rate during August. The two crops are mixed during maturity and harvest. Not enough samples of other summer crops existed to make conclusive comparisons.

The brightness means for sunflowers and corn are compared in figure 15. Both appear to follow the same brightness pattern. The brightness remains at a middle brightness range until both crops begin to mature; then the brightness declines.

From the study of sunflowers in six segments, they appear as a definite confusion crop with other summer crops in the scene and may even be hard to detect as a single category because of the variety of signatures within the crop itself.

3.5 RECOMMENDATIONS FOR COTTON, RICE, AND SOYBEANS

The analysis of the data collected on the new crops cotton, rice, and sunflowers resulted in the following recommendations.

The need for more developmental segments with 18-day ground truth observations for major crops in the scene is vital for further research. Ground truth 18-day observations for cotton and rice fields are available on some 1979 segments while this type of information for sunflower fields will not be available until the 1980 ground truth segments are processed. An effort needs to be made to compile ancillary information for each of the developmental crops. Crop information should also be gathered for the foreign areas to be studied during AgRISTARS.

The normal crop calendars need to be expanded to include all major crops within a segment. For example, the crop calendars for Mississippi contain no information on rice yet it is a major crop in the segments. Standardized growth stages need to be developed and used consistently in crop calendar development. A suggestion for cotton growth stages is shown in table 4.

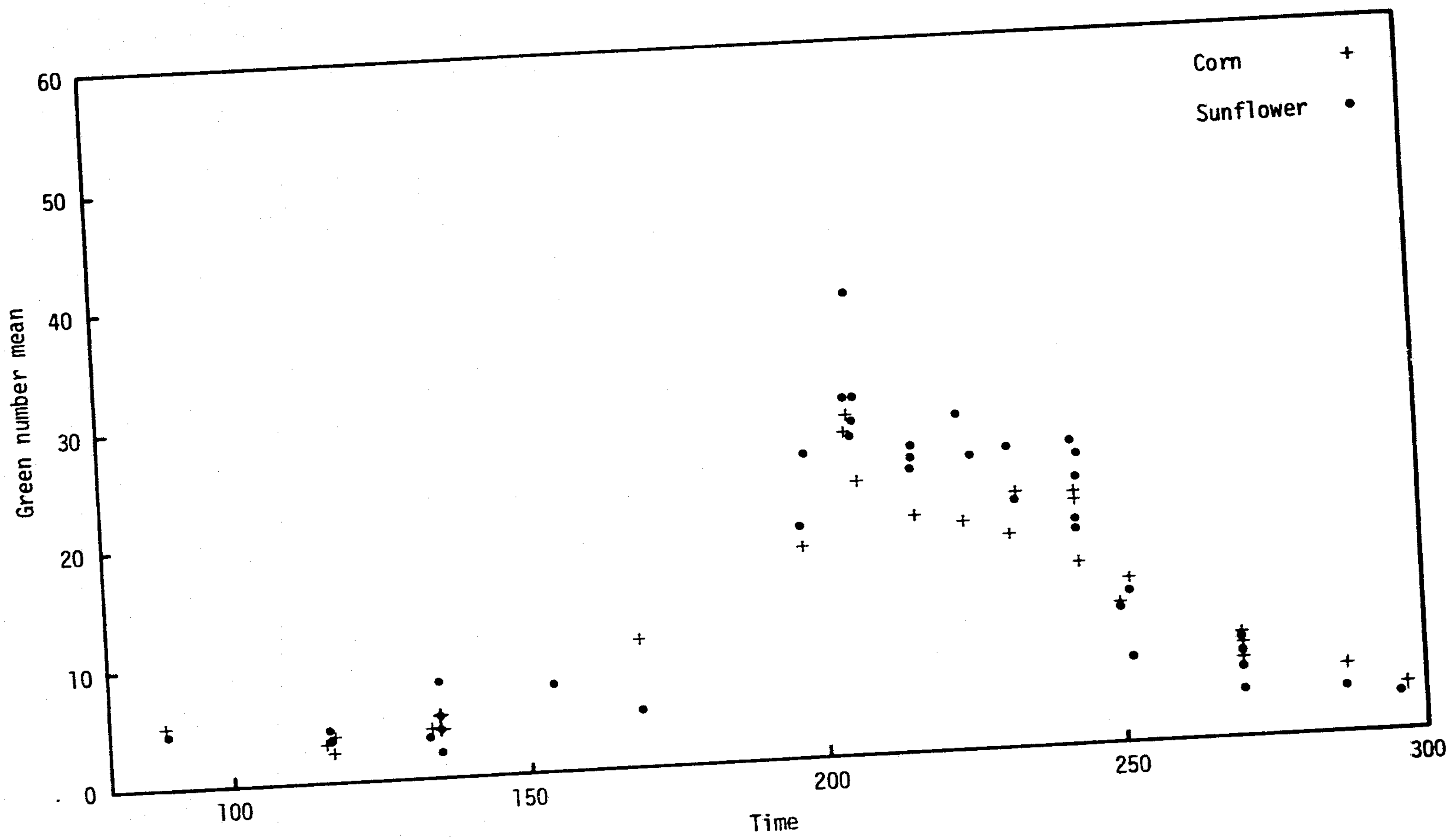


Figure 14.— Acquisition green number mean values for sunflowers and corn.

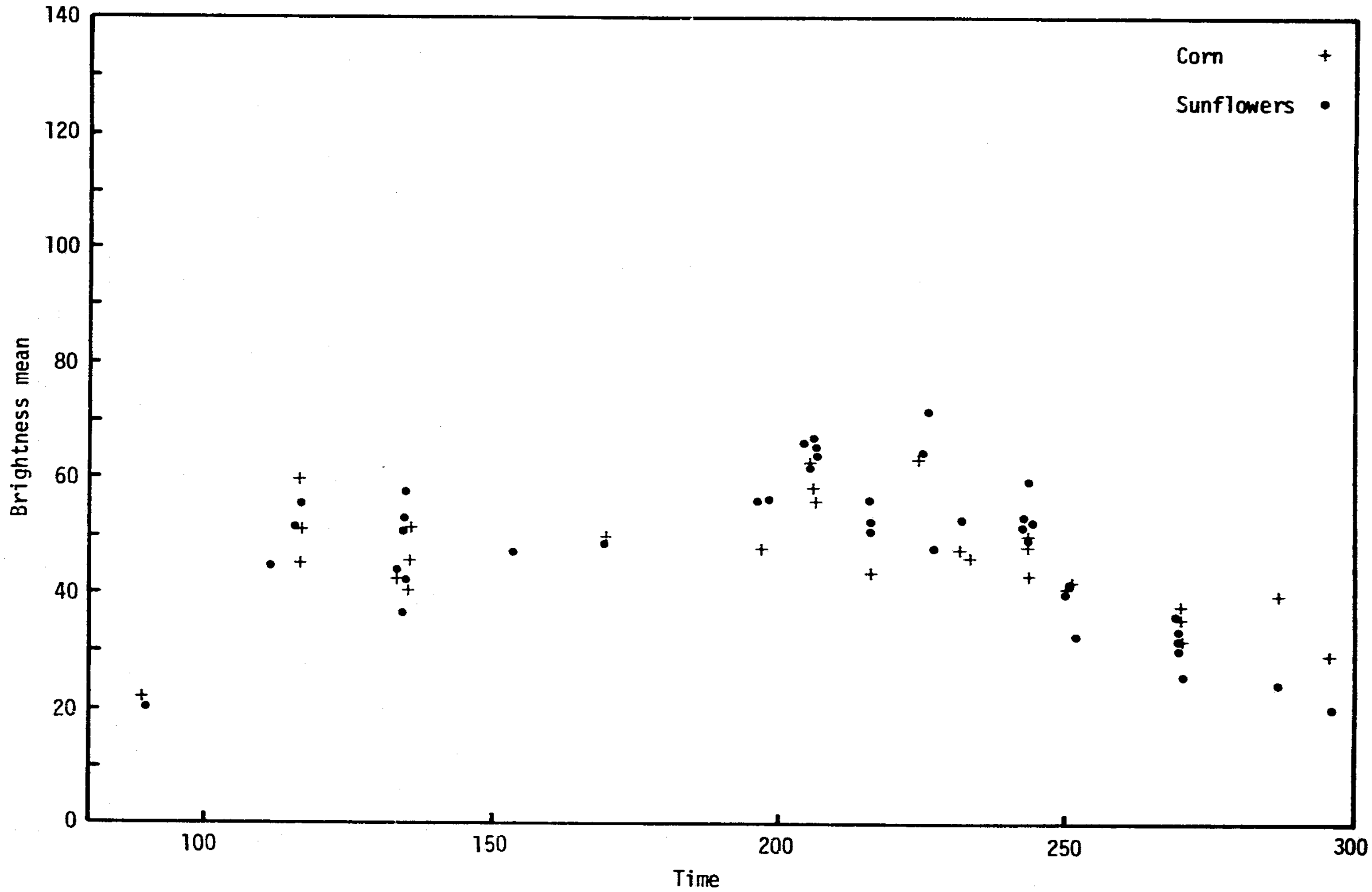


Figure 15.— Acquisition brightness mean values for corn and sunflowers.

TABLE 4.— RECOMMENDED COTTON GROWTH STAGES

Growth stage number	Cotton growth stage
1.0	Planting
2.0	Emergence
3.0	First square on plant
4.0	Blooming
5.0	First full boll
6.0	Fully open boll
7.0	Harvest

Stages presented in table 3 for the other crops appear sufficient for image analysis purposes.

More weather information than was available is needed for labeling research and development. Further investigation into crop stage information was undertaken during this study. At the state level, data were found using state weather and crop summaries. These included 1978 crop stage information for all the new crops, 10-year averages in Mississippi, and 5-year averages in Louisiana. This type of information can be used to construct usable crop calendars, as shown in figure 16a and b. The development of computerized crop calendars, which would allow current data to be stored and retrieved in graphic form and also to be updated with current year information, would be very helpful when doing research and testing. All of the generalized meterological data should be developed for new crops and more segment-specific data should be generated before any operational image analysis can be undertaken. Current year weather and crop stage information allows a better understanding of phenomena which occur in a particular segment and should be summarized for all major crops and made available for use in image analysis.

Analysis of the two film products (appendixes B and C) showed that, before July and after late August, product 3 was as good as or better than product 1 for field separation. However, in the summer months, all summer crops blend into the same shade of red on product 3. So product 1 should continue to be used for field discrimination and product 3 should be used to detect radical color distortions and used early and late in the growing season as a canopy indicator.

Examination of the spectral aids showed that the eight-acquisition green number versus brightness trajectories were not useful in distinguishing the new crops from other crops in the scene. The format used for these plots often obscured the true shape of the curve because acquisitions with similar green number/brightness values were overprinted. The time plots showed differences between summer and spring crops. However, curves of different summer crops were not easily distinguishable as the curves of corn and

1974-1978 Data USDA Louisiana Crop Summary

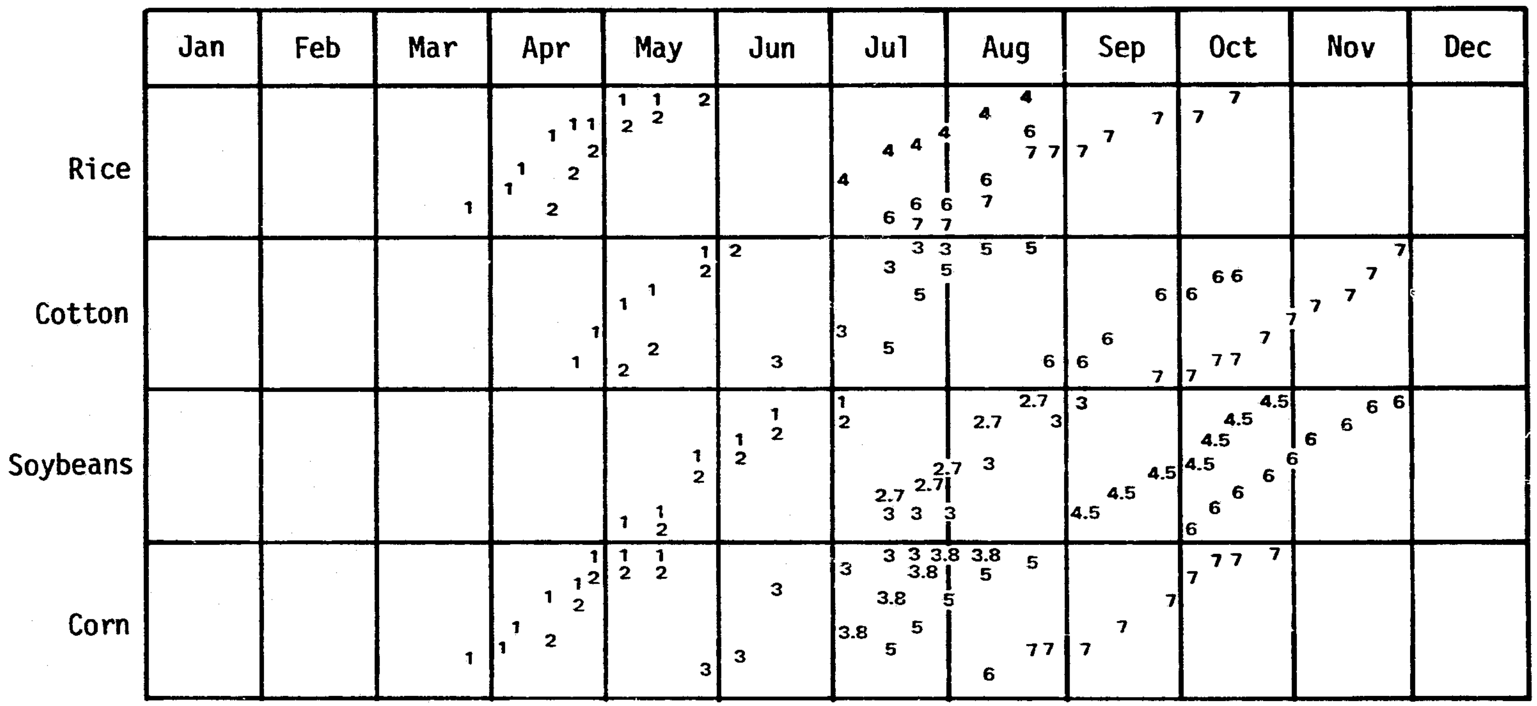
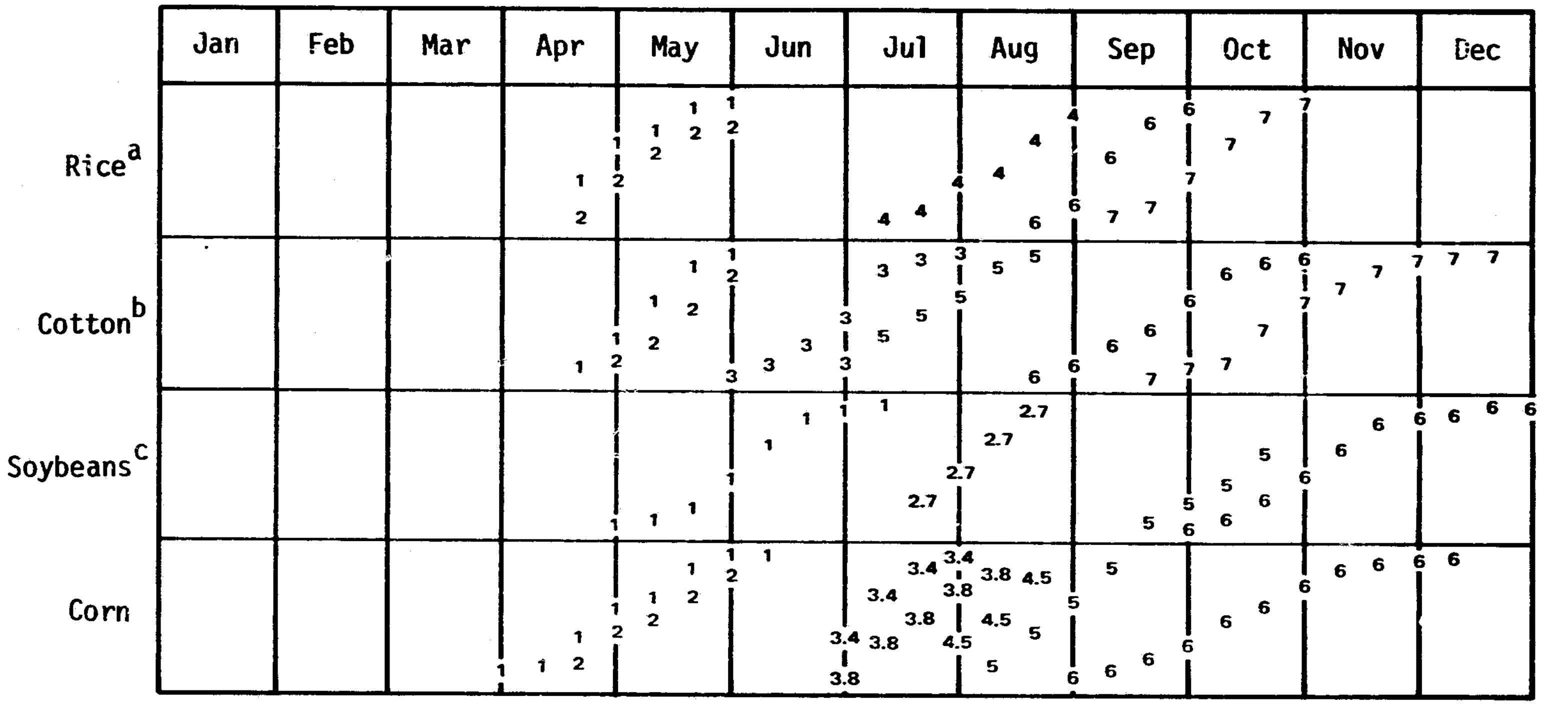


Figure 16a.— Recommended computerized crop calendar — Louisiana.

1969-1978 Data USDA Mississippi Weather and Crop Report



[a]Rice acreage doubled from 1977 to 1978.

[b]Cotton is largest cash crop in Mississippi. Mississippi ranks 3rd nationwide in cotton production.

[c]Mississippi ranks 8th in nation in soybeans. More acres of it than of any other crop. Increasing steadily.

Figure 16b.— Recommended computerized crop calendar — Mississippi.

soybeans were in the U. S. Corn Belt (ref. 1). No clear guidelines could be formulated for use of the scatter plots in the fringe areas except to distinguish spring crops from summer crops. On the basis of the analysis of current spectral aids, cotton and sunflowers appear to be confusion crops. New transformations and flexible display capabilities should be available in future research efforts before separation guidelines can be formulated. For example, the brightness means for cotton dots have a higher value generally than soybeans in every segment studied. This indicates a possibility of separating cotton, but current LACIE spectral aids were not developed to allow for exploring in different feature space. The cotton segments should be added to the LARS and OLPARS data bases so that further study can be initiated.

Unlike cotton, rice is distinguishable from the other summer crops at particular times of the year. The identification of rice can be accomplished in step 3 of the corn/soybean decision logic through the definition of a rice separation acquisition. It is recommended that the rice separation acquisition be defined as being open when the rice is at the jointing stage and closed when the rice goes into the heading stage. The rice separation acquisition will be within the early B biowindow. During the rice separation period, the rice will have full ground cover while the other summer crops will not be fully emerged. The rice could then be separated out because of the higher greenness of the plant. The flow of the decision logic is shown in figure 17. The analyst team would determine the natural break for definite rice in the data from both the imagery acquisition and the scatter plot within the rice separation biowindow. The separation biowindow definition would be dependent on the improvement of crop calendar information. Further development of green number ranges has to be completed before the scatter plot can be fully utilized.

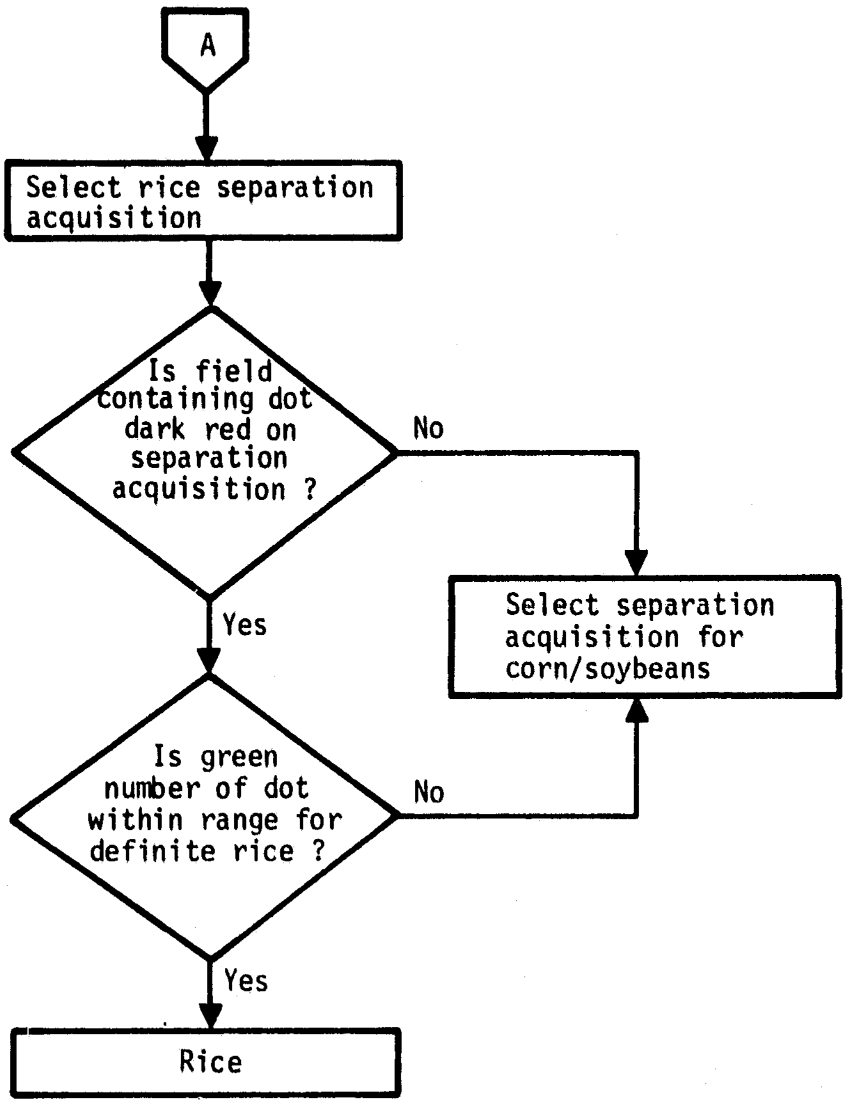


Figure 17.– Rice decision logic diagram.

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APPENDIX A

TRANSITION PROJECT CORN/SOYBEAN DECISION LOGIC

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TRANSITION PROJECT CORN/SOYBEAN DECISION LOGIC

A.1 SEPARATION OF MAJOR LAND-USE CATEGORIES – STEP 1

The decision tree for major land-use categories is displayed in figure A-1. The decision points on the diagram are keyed, by number, to the list of questions/decision criteria in section A.2.

A.2 DECISION CRITERIA FOR MAJOR LAND-USE CATEGORIES

The following questions are keyed to the decision points in figure A-1:

1. Is the area some shade of red (red, pink, brown, orange, etc.) on at least one acquisition?
2. Does the area appear to be water (dark blue-black to bright blue) on any of the acquisitions?
3. Is the area some shade of red on all acquisitions (i.e., no planting or harvest appearance)?
4. Is the area harvested (blue, green, white, gray, yellow) on an acquisition following the one on which it appeared red?
5. Is the area red or reddish brown throughout the year with the color most intense during the late spring or early summer? (Some trees lose their leaves annually and may appear dark brown during the winter.)
6. Is the area large and irregular?
7. Is the area large relative to the economic endeavor of the area, along a drainage network, and bright red in late spring and early summer and reddish brown or brown at other times?
8. Is the shape of the area similar to areas that have been identified as cropland and the color green or blue (may vary from dark to light during the year) on all acquisitions?

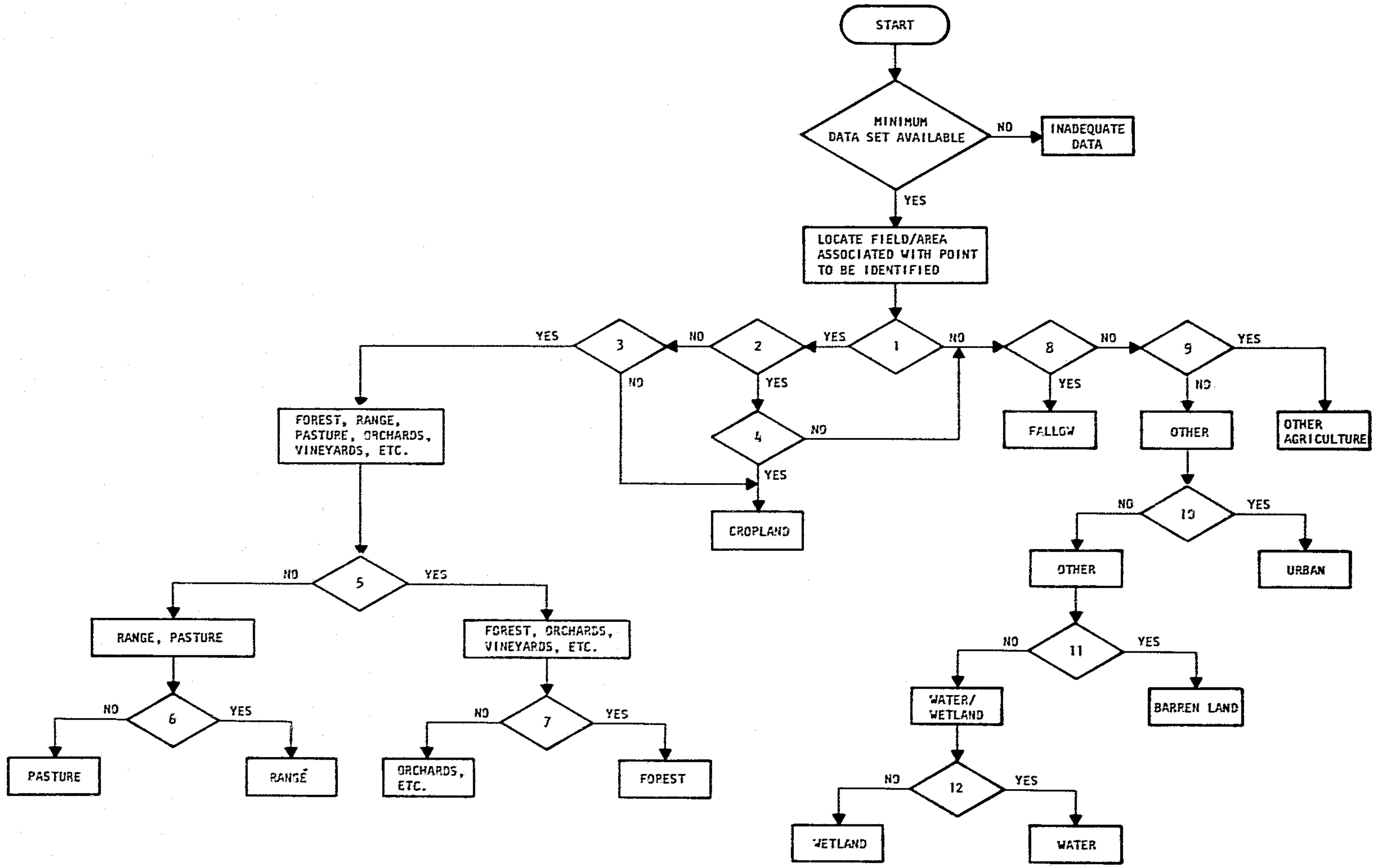

Figure A-1.– Diagram of decision logic for major land-use categories.

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9. Is the area small and white to dull gray?

10. Is the area irregular in shape and a constant white to mottled steel blue throughout the year?

11. Does the area appear to be constantly bright with no green vegetation and no seasonal change in shape or size?

12. Does the area appear dark blue-black to bright blue on all acquisitions? (Size and shape may change during year, but area is not seasonally wet.)

A.3 DEFINITIONS AND CHARACTERISTICS OF DECISION-TREE CATEGORIES

A.3.1 RANGE

This is uncultivated land that produces forage suitable for livestock grazing. Generally, it is land that is not suited for other types of agriculture, and the natural vegetation is predominantly grasslike plants, forbs, or shrubs. Most range in the United States is west of a north-south line that cuts through the Dakotas, Nebraska, Kansas, Oklahoma, and Texas.

Characteristics :

1. Large and irregular in Western United States
2. Vegetation indication varied, both within a specific area and between different areas; permanent with some seasonal change
3. No planting or harvest
4. Coarse texture
5. Red-brown to red in summer and a shade of gray in winter
6. Can occur in conjunction with and adjacent to cropland
7. Best detected in spring

A.3.2 PASTURE

A pasture is a fenced or unfenced tract of land on which farm animals feed by grazing. Generally, it is a grass area, but it may also have brush and trees. This category includes land used for feeding at a specific time in rotation with other uses; therefore, land in this situation could be pasture one year and cropland the next. It must be emphasized that the distinction between pasture and range is one of degree and location rather than of actual difference in use. Some definitions of pasture list range as a synonymous term.

Characteristics:

1. Shape varied; geometrical in Eastern and Central United States
2. Size small in Eastern United States, becoming larger westward
3. Easily confused with range
4. Color varied and mixed, ranging from mottled light pink or gray-brown to bright red on highly improved pastures
5. Seasonal changes; no planting or harvest unless new pasture being initiated or old one destroyed
6. Best detected in spring

A.3.3 ORCHARDS

An area or enclosure devoted to growing fruit, nuts, or certain forest products either as a commercial crop or for reseeding is categorized as an orchard. Isolated small enclosures used for these purposes on small farms would not be recognizable on Landsat imagery.

Characteristics:

1. Varied appearance, depending upon such variables as type of trees, spacing, age, canopy, time of year, and farming practices

2. May closely resemble forest – bright red in late spring and early summer, red-brown at other times
3. Size small in relation to forests
4. Shape and pattern generally regular
5. Area extent usually constant over long time periods

A.3.4 FOREST

A forest is a plant association predominantly of trees and other woody vegetation that occupies a rather extensive area.

Characteristics:

1. Shape, pattern, and size irregular
2. Generally follows terrain and drainage
3. No planting or harvest as with crops, but annual loss of leafage by certain trees
4. Area extent usually constant over long time periods
5. Bright red in late spring and early summer and reddish brown at other times; variation in intensity and shade

A.3.5 URBAN

This category is composed of areas that have much of the land covered by structures. It includes villages, towns, cities, strip developments, transportation and industrial areas, shopping centers, parks, cemeteries, golf courses, and sewage plants, as well as institutions that may, in some instances, be isolated from the main urban area. It also includes those areas that are strictly not urban but have been surrounded by urban development.

Characteristics:

1. Irregular in shape and area extent

2. Grid pattern within urban boundaries
3. White to a mixed mottled steel blue; constant through time
4. Texture usually extremely fine
5. Possible occurrence of irregularly shaped areas of light pink to medium red within urban area
6. Close correlation of pattern with urban outline on map
7. Transportation network associated with urban area basically white; can be constant through time

A.3.6 BARREN LAND

Barren land has a limited ability to support life. Generally, this is an area of thin soil, sand, or rock. Vegetation, if present, is more widely spaced and scrubby than that in the range category. Within this category are dry salt flats, sandy areas other than beaches, exposed rock, and extractive activities (e.g., strip mines, borrow pits, and gravel pits - either active or inactive) having significant surface expression (area).

<u>Characteristics</u>:

1. Bright and constant throughout year
2. Varied dark and light colors and tones
3. Irregular shape
4. Little or no vegetation
5. Size varied, ranging from minute (1 pixel) to extreme (1000 pixels or more)
6. No seasonal change in shape and size

A.3.7 OTHER AGRICULTURAL LAND

This category is for those items not classified under separate agricultural categories. It includes farmsteads, farm lanes and

roads, ditches, horse farms, confined feeding operations such as beef cattle and swine feedlots, dairy operations, and large poultry farms. Generally, these items are small in area, and it is doubtful that items of this nature can be interpreted on Landsat imagery as other than being a farm or farmstead.

Characteristics:

1. Color extremely varied and mixed; white to a dirty or off white for farmsteads and related activities
2. Area extent small
3. No green vegetation
4. No planting or harvest
5. Can occur in conjunction with and adjacent to cropland

A.3.8 WATER

This category refers to those areas persistently water covered. It includes rivers, streams, canals, lakes (natural and manmade), reservoirs, and bays and estuaries that extend inland.

Characteristics:

1. Irregular in shape except in some cases where manmade
2. May change slightly in shape and size during year
3. Should closely resemble shape and size on map, if mapped
4. Color varied, ranging from a dark blue-black to a bright blue, but usually some shade of blue throughout year
5. Smooth and uniform texture
6. No vegetation

A.3.9 CROPLAND

Cropland includes all land tilled for crops, as well as cultivated wetlands such as the flooded fields associated with rice production and developed cranberry bogs.

Characteristics:

1. Distinctive geometric field and road pattern in Central and Western United States; irregular and unsystematic in Eastern United States
2. Definite seasonal and intraseasonal changes in color; generally some shade of red or red-brown during growing season
3. Variation in color and intensity with crop type
4. Planting and harvest
5. Vegetation present but not permanent
6. Best detected in summer and early fall

A.3.10 FALLOW

This is cultivated land that may be kept free of vegetation by such methods as plowing and disking in order to destroy weeds or to conserve a supply of moisture for a succeeding crop.

Characteristics:

1. Shape and pattern similar to areas identified as cropland
2. No planting or harvest
3. Constant blue-green in color, but may vary from dark to light during year

A.3.11 WETLANDS

Areas where the water table is at, near, or above the land surface for a significant part of most years are categorized as wetlands. This category includes marshes, swamps, and tidal flats along the shallow margins of bays, lakes, rivers, and manmade impoundments or reservoirs, bogs, wet meadows, seasonally wet or flooded basins, playas, potholes, and wetland used for wildlife purposes. It does not include wetlands drained for any purpose or wetlands used for rice or similar types of production; these belong to other categories. Wetlands can be either forested or unforested.

Characteristics::

1. Highly varied appearance, both in color and intensity, depending upon such variables as vegetation type, wet or dry season, and winter or summer
2. Irregular in size and shape; not similar to areas identified as cropland
3. Intermittent water possible during year
4. No planting or harvest
5. Seasonally wet

A.4 CORN AND SOYBEAN SEPARATION

The corn and soybean separation process is divided into three steps:

Step 2 – Separation of cropland

Step 3 – Identification of definite corn and soybeans

Step 4 – Identification of remaining unlabeled dots

A.4.1 SEPARATION OF CROPLAND

In order to separate summer cropland from nonsummer cropland, all available acquisitions are sorted into biowindows using the corn and soybean normal crop calendars, the imagery, and the following definitions:

Bio-window	Definition†		Decription of expected characteristics
	Open on latest	Close on earliest	
A	C 30%>1 S 30%>1	C 80%>2 S 10%>2	Plowing, planting, pre-emergence, or very early emergence for summer crops
B	C 50%>3 S 10%>3	C 30%>5 S 10%>5	Full ground cover and green vegetation for summer crops
C	C 100%>5 S 100%>5	C 80%>6 +30 days S 80%>6 +30 days	Mature, harvest, and post-harvest for summer crops

Figure A-2 is a flow diagram for separating summer and nonsummer cropland. Fields that are bare soil (green, blue, white) on at least one acquisition in biowindow A, green vegetation (red, orange, pink, brown) on all acquisitions in biowindow B, and ripe and/or harvested (green, blue, white, yellow) on all acquisitions in biowindow C should be identified as summer crops.

Border and/or edge pixels are documented on the dot label form at this time.

†For example, entry C 30%>5 means that, according to the normal crop calendar, corn is 30 percent past stage 5 (maturity). Dates should be determined for both corn and soybeans and the latest used to open windows, the earliest to close windows.

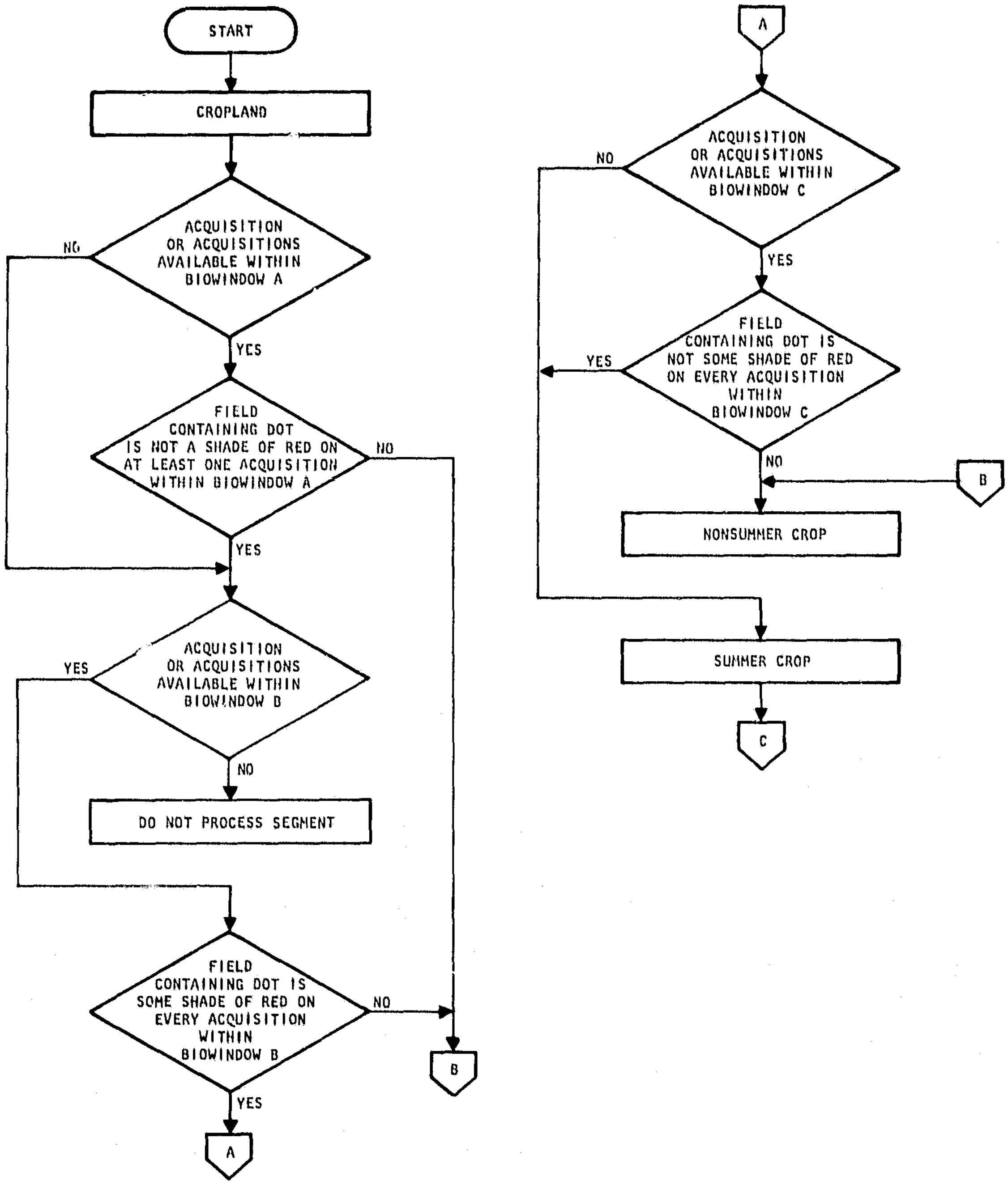

Figure A-2.— Diagram of decision logic for summer and nonsummer cropland separation (step 2).

A.4.2 IDENTIFICATION OF DEFINITE CORN AND SOYBEANS

The minimum data required for identifying corn and soybeans are one acquisition in biowindow A or biowindow C and one acquisition in a subset of biowindow B, called a separation biowindow and defined as follows:

Definition		Description of expected characteristics
Open on latest	Close on earliest	
C 90%>3 S 50%>3	C 30%>5 S 10%>5	Most of the corn is in the denting stage, and most of the soybeans are in the full pod stage.

Figure A-3 is a flow diagram of this step. The Analyst Team determines the natural break in the data depicted on the scatter plot in the separation biowindow and puts 5-count limitors in all directions, as shown in figure A-4.

All summer crop pixels that fall outside the limits in quadrant II are labeled soybeans, and all summer crop pixels that fall outside the limits in quadrant III are labeled corn. The summer crop pixels within the limitors (shaded area) are reserved for labeling in step 4.

A.4.3 IDENTIFICATION OF THE REMAINING UNLABELED DOTS

Two types of pixels are labeled in step 4. Edge pixels, if the separation acquisition is not the base acquisition, and the summer crop pixels that fall within the limitors in step 3 are labeled according to the flow diagram in figure A-5. Edge pixels are labeled according to the field that the dot is in on the base date. Definite corn and soybean fields are delineated and annotated on the imagery to provide a representative cross section of

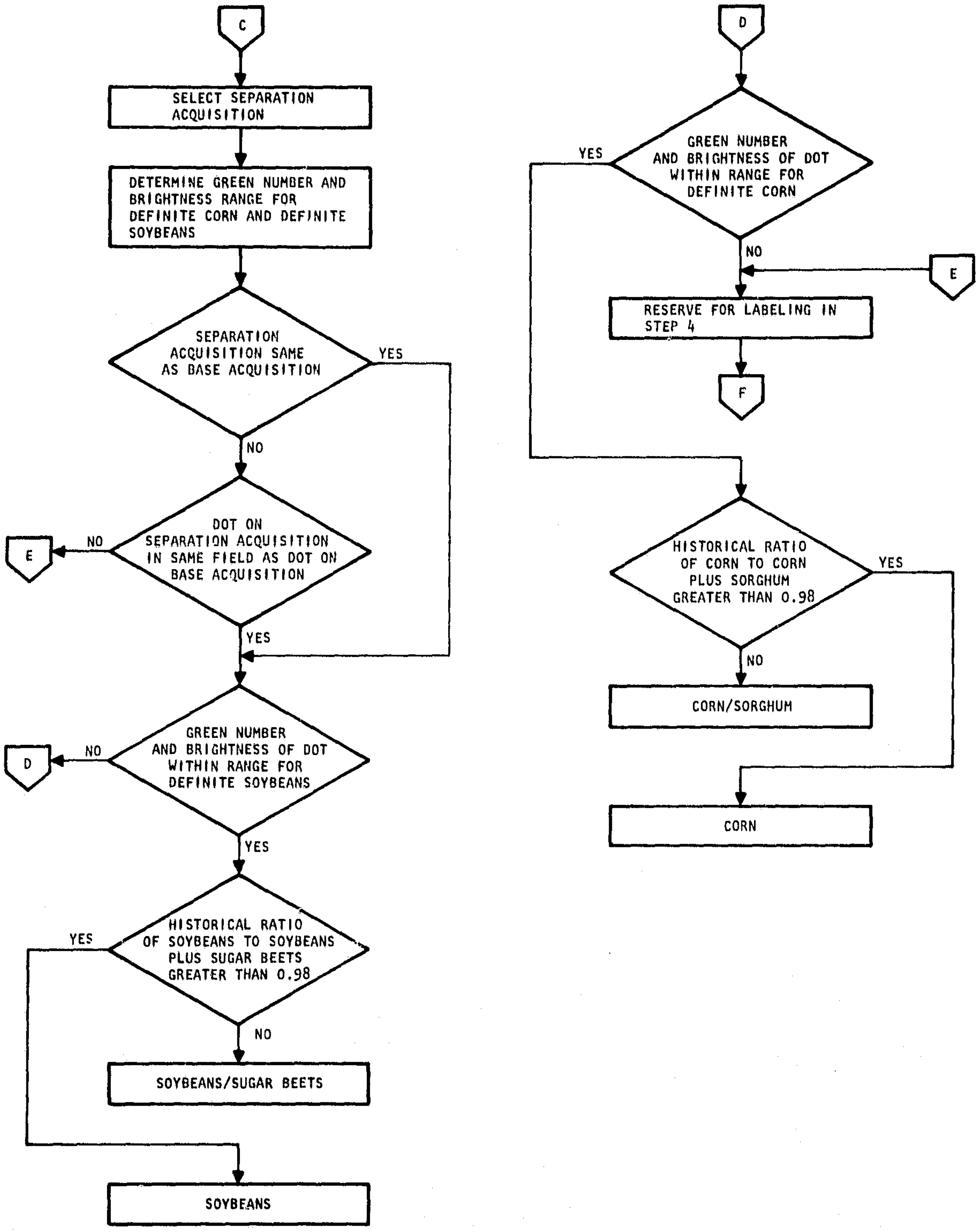

Figure A-3.— Diagram of decision logic for identifying definite corn and soybeans (step 3).

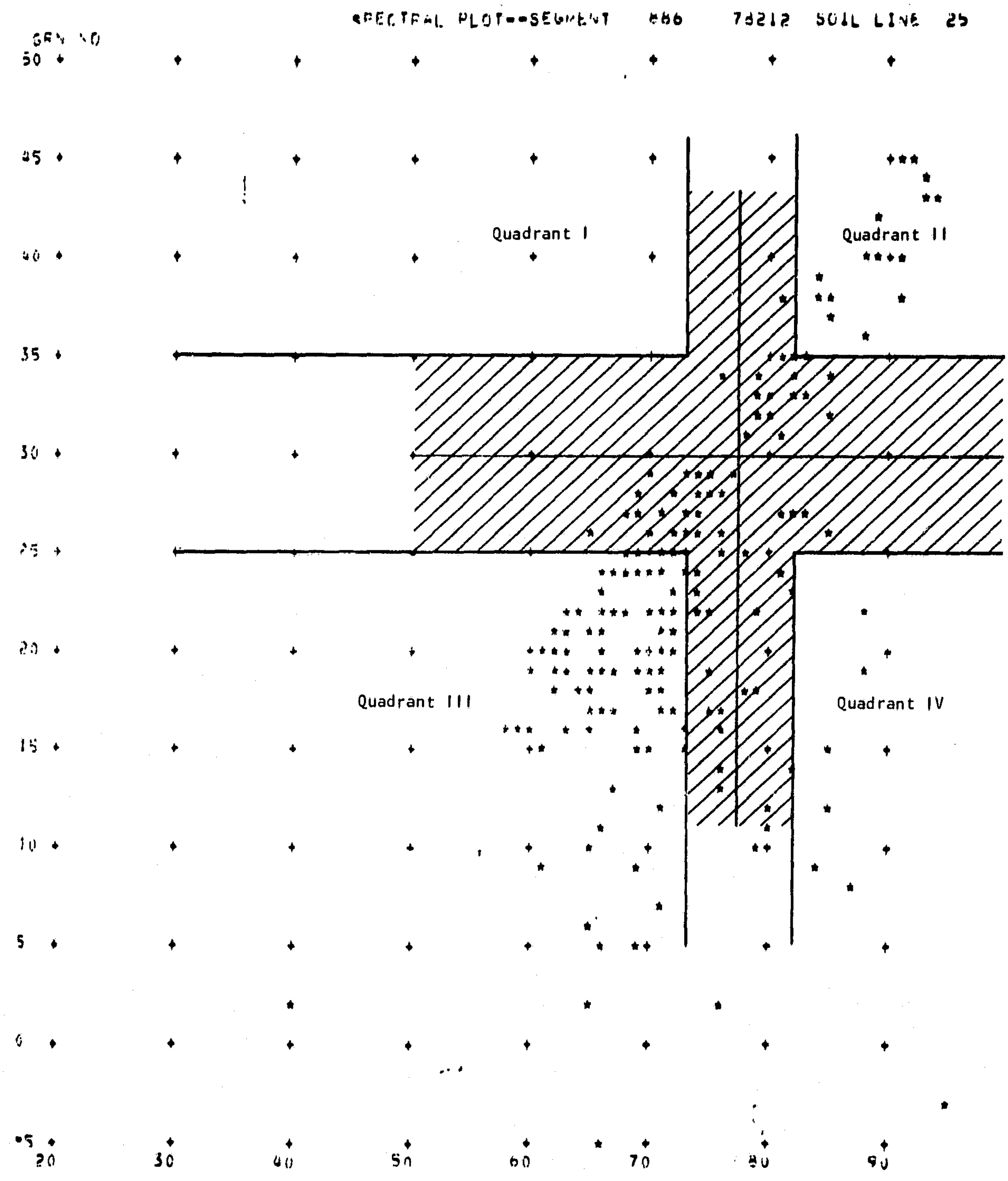

Figure A-4.— Delineation of break in data and limitors on scatter plot for step 3.

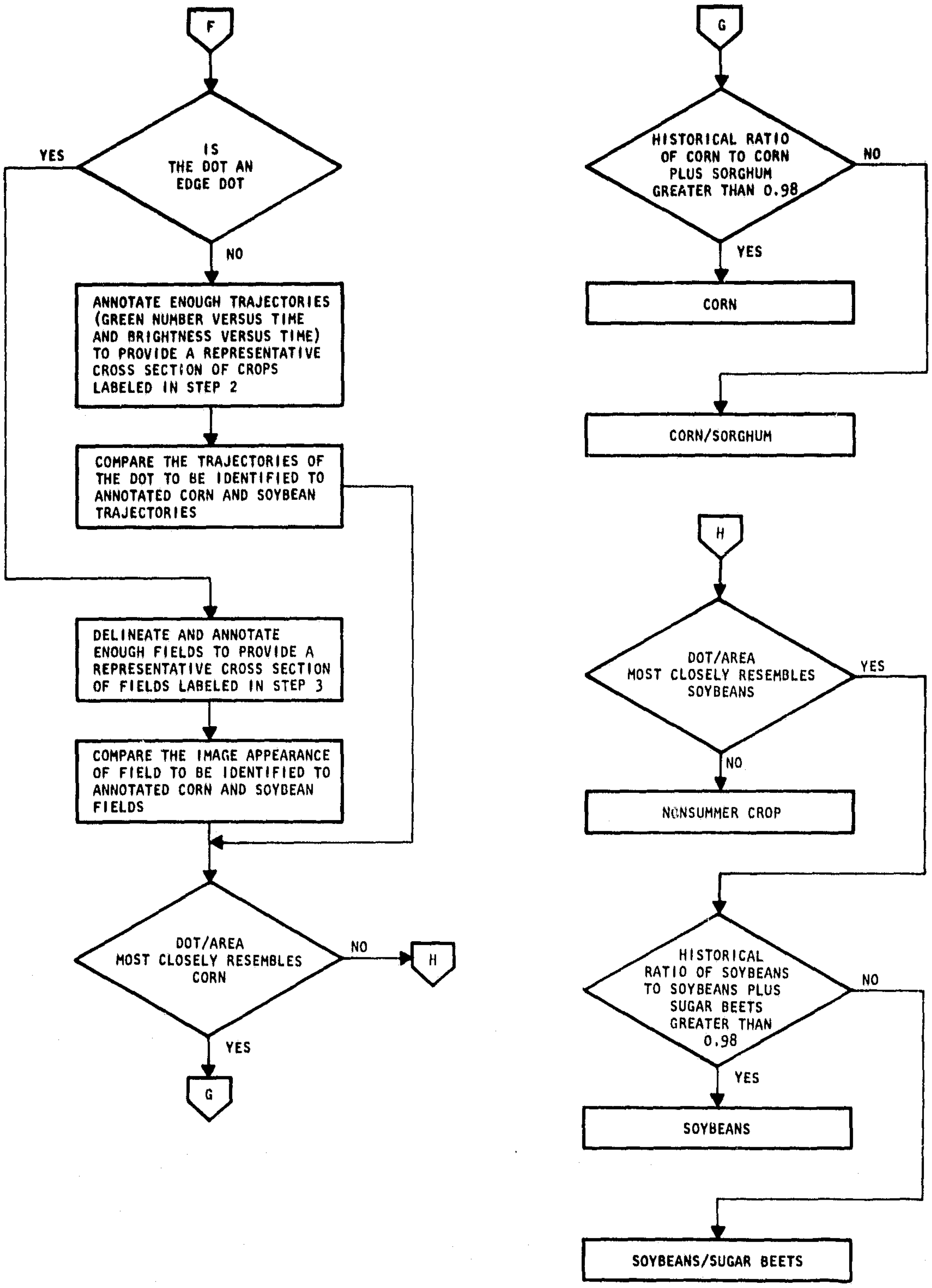

Figure A-5.— Diagram of decision logic for labeling remaining dots (step 4).

their signatures, and the unlabeled dots (edge pixel fields) are labeled to the category they most closely resemble. The dots that fall within the limitors of the scatter plot are labeled in a similar manner; however, the comparison is done using the green number versus time and brightness versus time trajectory plots instead of the imagery.

APPENDIX B

COTTON, RICE, AND SOYBEANS

TABLE B-1.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 174 (MOREHOUSE, LA.)

Segment no. 174	Acquisition date: 1 Apr. 8091	30 June 8181	18 July 8199	23 Aug. 8235	7 Oct. 8280	16 Oct. 8289	3 Nov. 8307
Soybeans							
Growth stage (historical)	0% > 1	10% > 2.5	20% > 3	100% > 3	25% > 5	25% > 6	95% > 6
Image appearance							
Product 1	Brown, dark pink	Dark green, pink	Bright red, pink, dr. green	Red, dark green	Red, brown	Red, brown, bright red	Bright red, brown, light brown
Product 3	Dark pink	Dark brown, pink	Bright red, dark green	Bright red, dark green	Bright red	Red, brown, bright red	Bright red, brown
Green number	8.85	6.11	11.25	20.35	15.20	13.65	7.74
Brightness	73.43	84.81	75.99	70.17	47.47	48.67	50.29
Cotton							
Growth stage (historical)	0% > 1	65% > 2	20% > 3	10% > 4	10% > 5	40% > 4	80% > 5
Image appearance							
Product 1	Light green, light brown	Pink, light green	Pink, light red	Pink, light red, orange	Pink, red, green	Pink, red, lt. brown, brown	Brown, light green
Product 3	Light green	Pink, light green	Pink, orange	Bright pink	Pink, bright red	Pink, brown, bright red	Brown, light green
Green number	5.59	11.50	26.77	40.67	18.75	16.27	7.87
Brightness	96.39	106.35	106.66	94.25	55.72	61.10	56.67
Rice							
Growth stage (historical)	0% > 1	10% > 4	40% > 4	20% > 6	75% > 6	20% > 7	100% > 7
Image appearance							
Product 1	Brown, dark pink	Dark red	Bright red, dark red	Light red, red	Light green, dark green	Dark green light green	Green, brown, gray
Product 3	Brown, dark pink, dark green	Dark red	Bright red, dark red	Bright red, pink	Light brown, dark brown	Brown, light brown	Light green, light brown
Green number	5.50	17.82	35.17	32.73	8.85	5.14	2.87
Brightness	58.53	76.06	69.62	75.97	47.55	46.77	45.90

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TABLE B-2.—OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 196 (SHARKEY, MISS.)

Segment no. 196	Acquisition date: 15 May 8135	18 July 8199	26 July 8207	23 Aug. 8235	19 Sept. 8262	7 Oct. 8280	16 Oct. 8289	24 Oct. 8297	2 Nov. 8306	12 Nov. 8316	17 Dec. 8351
Soybeans											
Growth stage (historical)	5% > 1	100% > 1	20% > 2.5	50% > 3	30% > 5	65% > 5	90% > 5	30% > 6	50% > 6	80% > 6	100% > 6
Image appearance											
Product 1	Green, brown-green	Light red, dark green	Red	Red, green, bright red	Orange, light red	Red, bright red, green	Bright red, brown, green	Light brown, dark green	Light brown, dark brown	Light brown, dark green	Light green, dark brown
Product 3	Green, brown	Red, bright red	Red, bright red	Red	Red	Red	Brown, bright orange	Brown, dark brown	Light brown, dark brown	Light green, dark green	Dark gray
Green number	11.9	14.25	20.88	23.81	18.7	13.96	9.14	5.3	3.8	4.1	3.2
Brightness	68.88	60.47	68.34	61.60	50.24	43.12	44.13	42.96	47.37	28.70	16.95
Cotton											
Growth stage (historical)	75% > 1	50% > 3	85% > 3	15% > 4	80% > 4	10% > 5	20% > 5	40% > 5	75% > 5	95% > 5	100% > 5
Image appearance											
Product 1	White, light green	Light green, pink	White, pink	Pink, light green	Light red	Light green	Light green, pink	Light green, pink	Light red, dark green	Light green	Light green, light brown
Product 3	Light green	Bright orange-red	Bright red, bright pink	Bright red	Red	Light red	Light red	Light red	Light brown, light green	Light green	Light brown, dark gray
Green number	8.3	12.44	16.71	20.72	16.4	11.37	10.46	8.5	6.21	5.31	3.68
Brightness	95.72	88.79	102.09	90.03	54.02	53.53	59.40	51.57	61.77	42.64	25.16
Rice											
Growth stage (historical)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Image appearance											
Product 1	Brownish green	Red-brown	Red	Light red	Light green	Light green	Light green, dark green	Light green	Light green, dark green	Light green	Light green
Product 3	Dark green	Bright red	Red	Bright red	Light red	Light red	Light brown, brown	Light brown	Light green	Light green, dark green	Dark brown, dark gray
Green number[a]											
Brightness[a]											

[a]Not available because of small number of dots in category.

TABLE B-3.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 198 (TUNICA, MISS.)

Segment no. 198	Acquisition date 6 May 8126	15 May 8135	29 June 8180	18 July 8199	23 Aug. 8235	19 Sept. 8262	6 Oct. 8279	16 Oct. 8289	24 Oct. 8297	3 Nov. 8307	[a]17 Dec. 8351
Soybeans											
Growth stage (historical)	Pre 1.0	Pre 1.0	100% > 1.0	30% > 2.5	70% > 2.5	20% > 5.0	60% > 5.0	10% > 6.0	30% > 6.0	55% > 6.0	
Image appearance											
Product 1	Green	Green/ white	Green/ faint pink	Red/lt. red	Red	Red	Red	Greenish brown/red	Brown/ red	Brown/ green	
Product 3	Green	Yellow/ green	Green/ faint red	Red/lt. red	Red	Red	Red	Red/ reddish brown	Brown	Green	
Green number	-37.65	6.57	6.54	16.14	29.37	21.83	16.60	9.33	6.56	3.22	2.60
Brightness	78.81	69.74	82.32	71.47	63.99	52.90	49.42	46.24	41.35	43.80	19.94
Cotton											
Growth stage (historical)	50% > 1.0	80% > 1.0	65% > 2.0	20% > 3.0	10% > 4.0	70% > 4.0	95% > 4.0	25% > 5.0	50% > 5.0	75% > 5.0	
Image appearance											
Product 1	Green	Green/white	Green/faint pink/yellow-green	Mottled red/green	Mottled red/lt. red (white)	Mottled green/red	Mottled green/red	Mottled red/ brown	Mottled pink/white	Brown	
Product 3	Green	Yellow/ green	Green/ faint red	Mottled red/ faint red	Mottled lt. red (reddish yellow)	Mottled red	Mottled red/ lt. red	Mottled reddish brown	Mottled red/ brown	Green	
Green number	-39.10	7.05	8.44	16.79	30.84	17.83	15.42	11.42	8.08	6.15	3.13
Brightness	87.17	94.01	100.33	87.74	84.47	52.89	59.94	52.07	50.16	49.29	22.18
Rice											
Growth stage (historical)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Image appearance											
Product 1	Green	Dark green/ white	Green/pink (lt. red), red	Red	Red (pinkish red)	Pinkish red/ green	Red/ green	Red/ white	Red/ white	Red/ white/ green	
Product 3	Green	Dark green/ yellow	Red/faint red	Red	Red	Red/ lt. red	Red/ tan	Red/ yellow	Red/ yellow	Green/ lt. red	
Green number	-38.83	7.58	17.77	30.60	35.10	15.29	10.84	7.66	5.84	3.01	2.26
Brightness	80.10	72.67	69.91	63.02	70.05	55.32	52.59	66.67	53.67	52.41	20.17

[a]Poor imagery.

TABLE B-4.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 200 (YAZOO, MISS.)

	Acquisition date							
Segment no. 200	15 May 8135	26 July 8207	4 Aug. 8216	22 Aug. 8234	6 Oct. 8279	24 Oct. 8297	2 Nov. 8306	17 Dec. 8351
Soybeans								
Growth stage (historical)	5% > 1	20% > 2.5	50% > 2.5	50% > 3	65% > 5	30% > 6	50% > 6	100% > 6
Image appearance								
Product 1	Green	Orange red, green	Orange red	Orange red	Orange red, light green, dark green, tan	Light green, olive green	Olive, light green	Bluish green
Product 3	Light green, dark green	Red, pink	Orange red	Orange red	Red, yellow, dark red	Purple, grayish purple	Light gray	Light & dark purple
Green number	8.05	16.86	23.52	30.87	12.68	4.17	4.86	3.56
Brightness	77.65	68.58	83.79	71.57	47.41	42.68	55.54	25.21
Cotton								
Growth stage (historical)	75% > 1	85% > 3	100% > 3	10% > 4	95% > 4	40% > 5	72% > 5	100% > 5
Image appearance								
Product 1	Green	Light green, tannish green	Olive green, light green	Olive green, light green	Light green, olive green	Greenish tan	Light brown	Olive green, light green
Product 3	Light green, dark green	Dark red, yellowish red	Yellowish red	Light red, yellowish red	Red	Pinkish purple	Mottled pink, tan & purple	Light & dark purple
Green number	6.66	14.39	19.04	23.90	9.34	8.04	8.69	4.04
Brightness	85.90	77.23	91.01	83.69	50.48	49.30	56.71	26.46

TABLE B-5.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 812 (BOLIVAR, MISS.)

Segment no. 812	Acquisition date: 1 Apr. 8091	30 June 8181	18 July 8199	26 July 8207	14 Aug. 8226	23 Aug. 8235	31 Aug. 8243	6 Oct. 8279	7 Oct. 8280	16 Oct. 8289	3 Nov. 8307	12 Nov. 8316
Soybeans												
Growth stage (historical)	70% > 1	85% > 1	100% > 1	15% > 2.5	30% > 3	40% > 3	60% > 3	55% > 5	55% > 5	80% > 5	40% > 6	75% > 6
Image appearance												
Product 1	Light green, grayish green	Green, green w/ dark red mottling	Dark green, red, mottled green & red	Red, green, mottled red & green	Red with tan flecks, greenish purple	Red, dark red, purple	Red, tannish red	Red, dark red	Dark tannish red, & purplish red	Red, dark tannish red, dark olive	Olive, dark red	Olive, dark purple, light olive
Product 3	Light green, dark green, tannish green	Dark green, pink, reddish purple	Green purple, red, pink	Red, dark red, greenish red	Red, dark red	Red, dark red	Red	Red, dark red, purplish red	Dark red, purplish red	Brownish red, dark tan	Mottled brown, dark green, yellowish tan	Olive brown, yellowish purple, dark green
Green number	5.26	5.73	19.85	19.35	25.80	32.16	N/A	N/A	15.52	9.18	3.86	4.14
Brightness	61.90	76.09	70.69	64.41	60.11	68.67	N/A	N/A	44.23	41.84	45.00	39.46
Cotton												
Growth stage (historical)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Image appearance												
Product 1	White, dark green	Light green	Light green, brownish red	Light green, mottled red & green	Mottled dark red, mottled green	Dark red, pink	Purple	Tannish red, purple	Tannish red, purple	Tannish red, purple	Tannish, purple	Purple, dark olive
Product 3	White, light green	Light green, tannish green	Tannish red, yellowish tan	Reddish tan, red	Red	Red, light red	Red	Light red	Light red, dark red	Light red, dark tan	Yellowish tan, mottled brown	Olive brown, purplish
Green number	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Brightness	77.41	101.71	83.37	78.93	68.01	89.28	N/A	N/A	52.27	54.39	51.66	42.46
Rice												
Growth stage (historical)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Image appearance												
Product 1	Grayish green, light green	Bright red, dark red, red	Bright red, brownish red	Brownish red, purple	Purple, green, dark red, mottled green, red & tan	Light green, purple	Green, tan, purple	Light green, green, brownish green	Light green, green, dark green	Light green, green, dark green	Light green, green, dark green	Light green, green
Product 3	Dark green	Red, purple	Red, dark red	Red, dark red	Red, dark red	Light green, red, dark red, tannish red	Red, light green, light red	Light green, dark green, yellowish tan	Light green, dark green, yellowish tan	Light green, green	Light green, green	Light green, green
Green number	4.14	20.83	33.80	23.22	19.38	21.26	N/A	N/A	5.89	3.66	3.20	3.80
Brightness	53.31	74.91	66.99	61.50	58.44	73.23	N/A	N/A	51.25	55.96	51.96	44.09

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APPENDIX C

SUNFLOWERS, WHEAT, CORN, AND SOYBEANS

TABLE C-1.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 185 (TRAVERSE, MINN.)

Segment no. 185	Acquisition date: May 13 8133	June 18 8169	July 16 8197	July 24 8205	Aug. 2 8214	Aug. 12 8224	Aug. 20 8232	Aug. 29 8241	Sept. 7 8250	Oct. 14 8287	Oct. 23 8296
Sunflowers											
Growth stage (historical)	NA	100% > 1.0	NA	NA	NA	NA	NA	NA	NA	7.0	7.0
Image appearance											
Product 1	Green, gray	Green	Green, purple, pink	Green, purple, br. pink	Br. pink, red	Pink, red	Red	Red	Purple, red, br.red, brown	Dark & light gray, brown	Gray
Product 3	Green, gray	Gray	Bright red, purple pink	Red, br. red	Br. red	Red, br. red	Red, br. red	Red	Purple, red, pink	Gray, khaki	Gray
Green number	2.94	4.95	19.70	30.42	NA	28.30	25.18	NA	12.24	4.11	3.03
Brightness	44.53	49.20	56.73	73.20	NA	65.93	54.19	NA	41.12	25.37	21.73
Wheat											
Growth stage (historical)	80% > 1.0	75% > 3.5	90% > 4.0	80% > 5.0	100% > 5.0	40% > 7.0	60% > 7.0	100% > 7.0	7.0	7.0	7.0
Image appearance											
Product 1	Red, gray, green	Red	Red, tan, brown	Brown, red, green	Green, brown	Brown, white, gray, green	Yellow green, gray	Green, gray	Gray, green	Gray, green	Gray
Product 3	Red, purple, gray	Red	Red	Red, br. red, brown	Purple, brown	Gray, khaki, green, gold	Gray, yellow, green	Green, gray	Gray	Gray	Gray
Green number	3.12	38.30	17.62	19.86	NA	9.51	7.09	NA	4.84	3.54	3.05
Brightness	36.77	67.77	49.31	61.10	NA	69.44	58.83	NA	35.89	24.21	22.60
Corn											
Growth stage (historical)	20% > 1.0	80% > 2.0	30% > 3	50% > 3	60% > 3	20% > 4	25% > 4	30% > 4	40% > 4	30% > 6	60% > 6.0
Image appearance											
Product 1	Gray, pink, green	Green	Red, green	Red, brown	Red	Green, red	Red, purple	Red	Purple, brown	White, gray,	White, gray
Product 3	Green, gray, pink	Gray, purple	Red, br. red	Red	Red, br. red	Gold, red	Red, purple	Red	Red	White, gray	Yellow, gray
Green number	-2.51	6.51	18.63	25.30	NA	14.23	12.82	NA	5.92	0.33	-2.41
Brightness	43.06	50.39	48.27	63.85	NA	64.68	47.77	NA	41.34	40.23	30.15
Soybeans											
Growth stage (historical)	0.0	20% > 2.0	20% > 3	20% > 3	30% > 3	70% > 3.0	25% > 4	30% > 4	40% > 4	40% > 6	90% > 6.0
Image appearance											
Product 1	Green	Green	Gray, pink, red, br. red	Pink, red, purple	Red, br. pink, gray	Br. red	Br. red, red	Br. red, red	Green, yellow br. red	Yellow gray	Gray
Product 3	Green, gray	Gray, pink	Red, br. red	Br. red	Br. red, red	Red, br. red	Br. red	Br. red	Br. red		Gray
Green number	2.49	6.77	23.53	36.26	NA	37.61	33.92	NA	19.28	3.78	3.43
Brightness	46.86	48.49	57.95	75.43	NA	72.93	63.56	NA	51.40	30.16	26.02

TABLE C-2.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 1472 (BARNES, N. DAK.)

	Acquisition date					
Segment no. 1472	27 Apr. 8117	15 Mar. 8135	4 Aug. 8216	31 Aug. 8243	9 Sept. 8252	27 Sept. 8270
Sunflowers						
Growth stage (historical)	NA	NA	NA	NA	NA	NA
Image appearance						
Product 1	Green	Green	Red, bright orange	Red, bright red	Pink, brown	Dark green, dark gray
Product 3	Green	Green	Brilliant red	Reddish	Brown	Brown
Green number	4.76	7.85	25.88	19.12	NA	6.26
Brightness	55.82	51.96	53.82	54.29	NA	31.63
Spring wheat						
Growth stage (historical)	50% > 1	10% > 2	90% > 5	80% > 7	100% > 7	
Image appearance						
Product 1	Dark green	Green	Mottled red/ green	Olive green	Yellow green	
Product 3	Green Haze	Green	Reddish	Green	Yellow, beige	
Green number	4.10	5.07	12.63	5.70	NA	4.20
Brightness	57.65	52.10	46.94	58.38	NA	33.43
Corn						
Growth stage (historical)	100% < 1.0	10% > 1.0	60% > 3.0	10% > 4.2	10% > 5.0	50% > 6.0
Image appearance						
Product 1	Green	Green	Brownish red	Brownish red, lavender	Light green, brown	Dark green, yellow
Product 3	Green	Green	Red	Red	Beige	Mottled green
Green number	3.72	5.41	20.23	16.07	NA	6.97
Brightness	60.33	46.28	44.74	49.60	NA	32.62

TABLE C-3.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 1619 (GRAND FORKS, N. DAK.)

Segment no. 1619	Acquisition date May 15 8135	July 17 8198	July 26 8207	Aug. 4 8216	Aug. 31 8243	Sept. 9 8252	Sept. 27 8270
Sunflowers							
Growth stage (historical)	NA	NA	NA	NA	NA	NA	NA
Image appearance							
Product 1	Green, gray	Red, bright red or pink	Pinkish red	Red	Bright pink, red, brown	Purple, tan, brown, green	Green, gray
Product 3	Green, gray	Bright red	Bright red	Bright red	Bright red, pink, brown	Red, purple, brown	Purple, gray, green
Green number	2.59	26.63	39.18	24.51	18.51	7.50	4.30
Brightness	36.45	56.96	67.19	52.53	50.13	34.18	26.30
Spring wheat							
Growth stage (historical)	60% > 2.0	75% > 4.0	40% > 5.0	75% > 5.0	75% > 7.0	95% > 7.0	100% > 7.0
Image appearance							
Product 1	Green, gray, purple	Red, dull red, brown	Brown, green, brick	Green, brown, white	Green, gray, yellow	White, green, gray, black	Gray, green, black, white
Product 3	Green, gray, purple	Red, brownish red	Brown, green brick	Khaki, brown	Green, yellow, gray	Green, yellow, gray, black	Gray, black, green, pink
Green number	4.04	17.38	14.26	7.13	2.77	3.32	3.60
Brightness	34.71	48.57	49.66	55.39	40.14	31.07	26.16
Corn							
Growth stage (historical)	0.0	NA	25% > 3.0	50% > 3.0	25% > 4.0	65% > 4.0	75% > 5.0
Image appearance							
Product 1	Green, gray	Red	Red	Red, brownish red	Brown, red	Brown, orange, red	Yellow, green
Product 3	Green, gray	Bright red	Red	Bright red	Brown,red	Brown, orange, red	Tan, brown
Green number	NA	NA	NA	NA	NA	NA	NA
Brightness	NA	NA	NA	NA	NA	NA	NA

TABLE C-4.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 1658

(DICKEY, N. DAK.)

Acquisition date

Segment no. 1658	27 Apr. 8117	15 May 8135	26 July 8207	31 Aug. 8243	9 Sept. 8252	27 Sept. 8270
Sunflowers						
Growth stage (historical)	NA	NA	NA	NA	NA	NA
Image appearance						
Product 1	Dark green	Green	Red, orange, bright red	Variations of red	Beige, green, brown	Mottled green, brown, red
Product 3	Hazy green	Olive green	Red	Red	Red, bright beige	Mottled
Green number	3.57	4.65	30.71	25.09	13.51	7.79
Brightness	51.89	53.93	65.07	53.64	41.98	34.38
Spring wheat						
Growth stage (historical)	20% > 2.0	10% > 3.0	70% > 5.0	90% > 7.0	100% > 7.0	
Image appearance						
Product 1	Green	Green, pink	Dull red	Green	Green, mottled	
Product 3	Hazy green	Olive green	Red	Shades of red	Red & golden	Mottled
Green number	4.24	4.89	23.64	8.70	7.02	5.30
Brightness	50.65	51.65	56.96	57.09	47.93	37.29
Corn						
Growth stage (historical)	1.0	80% > 1.0	40% > 3.0	40% > 4.0	80% > 4.0	30% > 6.0
Image appearance						
Product 1	een	Green	Reddish brown, bright red	Red to dull red	Brown to golden	Golden, green, brown
Product 3	Hazy green	Olive green	Red	Red	Red to beige	Mottled
Green number	3.02	5.37	25.67	21.88	14.21	8.54
Brightness	51.09	51.59	56.94	51.10	43.64	37.60

TABLE C-5.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 1664 (SARGENT, N. DAK.)

Segment no. 1664	Acquisition date 27 Apr. 8117	14 & 15 May 8134 & 8135	25 July 8206	21 Aug. 8233	31 Aug. 8243	26 & 27 Sept. 8269 & 8270
Sunflowers						
Growth stage (historical)	NA	NA	NA	NA	NA	NA
Image appearance						
Product 1	Green	Green	Variation of pink, red & orange	Bright orange & mottled red	Bright red to dull pink	Green, brown, mottled red
Product 3	Olive green	Dark green	Red	Shades of red	Shades of red	Mottled
Green number	3.34	4.40	27.45	21.45	26.30	7.88
Brightness	45.69	43.50	67.68	49.14	53.00	33.46
Spring wheat						
Growth stage (historical)	50% > 1.0	90% > 2.0	70% > 5.0	90% > 6.0	90% > 7.0	100% > 7.0
Image appearance						
Product 1	Green	Shades of green	Dark red to mottled red	Shades of green	Green, yellow, gray	Mottled green, gold
Product 3	Olive green	Dark green	Mottled red	Beige	Dark green & golden	Mottled green
Green number	3.64	4.09	20.05	7.93	7.93	5.13
Brightness	43.24	44.19	61.32	56.21	42.88	34.87
Corn						
Growth stage (historical)	1.0	70% > 1.0	40% > 3.0	20% > 4.0	50% > 4.0	80% > 5.0
Image appearance						
Product 1	Green	Green	Mottled red	Reddish brown	Brown & purple	Mottled green & golds
Product 3	Dark green	Dr. green & red	Red	Beige & golden	Brown	Mottled gray
Green number	2.95	4.31	28.78	21.85	21.19	8.01
Brightness	45.68	41.42	58.77	46.76	43.83	38.61

TABLE C-6.— OBSERVED CHARACTERISTICS FOR MAJOR CROPS IN SEGMENT 1924 (LA MOURE, N. DAK.)

Segment no. 1924	Acquisition date: 15 & 16 May 8135 & 8136	3 June 8154	17 July 8198	26 & 27 July 8207 & 8208	4 & 5 Aug. 8216 & 8217	14 Aug. 8226	31 Aug. 8243	9 Sept. 8252	27 Sept. 8270
Sunflowers									
Growth stage (historical)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Image appearance									
Product 1	Green	Green/ pink, red	Red	Bright orange	Red, bright orange	Red, bright orange, beige	Mottled red, bright red, orange	Pink, brown	Brown, dark gray, green, pink, red
Product 3	Olive green	Dark olive	Red	Red	Very red	Mottled red	Variation of red	Mottled red	Red, pink, brown
Green number	5.71	7.59	NA	28.42	25.34	25.22	22.89	NA	8.55
Brightness	58.69	48.43	NA	66.74	56.95	72.59	60.26	NA	37.55
Spring wheat									
Growth stage (historical)	80% > 2.0	70% > 3.0	40% > 5.0	80% > 5.0	20% > 6.0	50% > 7.0	100% > 7.0	7.0	7.0
Image appearance									
Product 1	Green, very light red	Light red to red	Red	Red to mottled red & green	Brownish green	Golden	Green		
Product 3	Dark green	Red	Red	Red	Red	Mottled red	Green	Mottled	
Green number	4.16	9.00	NA	23.49	16.33	12.52	6.91	NA	5.46
Brightness	57.13	53.90	NA	58.34	51.49	83.59	62.52	NA	38.19
Corn									
Growth stage (historical)	30% > 1.0	90% > 1.0	10% > 3.0	50% > 3.0	80% > 3.0	10% > 4.0	50% > 4.0	10% > 5.0	70% > 5.0
Image appearance									
Product 1	Green	Pale pinks, green	Red	Degrees of red	Red	Shades of red	Reds to brown	Shades of red & brown	Shades of mottled, red, brown, greens
Product 3	Olive green	Dark green	Red	Red	Shades of red	Red	Reddish brown	Red	Mottled
Green number	NA	NA	NA	NA	NA	NA	NA	NA	NA
Brightness	NA	NA	NA	NA	NA	NA	NA	NA	NA